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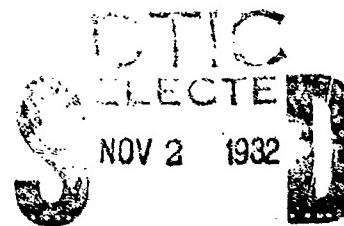
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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD REPORT No. 702

Compendium of
Unsteady Aerodynamic Measurements



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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT
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AGARD Report No.702
COMPENDIUM OF UNSTEADY AERODYNAMIC MEASUREMENTS

This Report was sponsored by the Structures and Materials Panel of AGARD.

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Published August 1982

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ISBN 92-835-1430-0



Printed by Technical Editing and Reproduction Ltd
5-11 Mortimer Street, London WIN 7RH

PREFACE

The Subcommittee on Aeroelasticity of the AGARD Structures and Materials Panel (SMP) has produced two recent publications on the AGARD Standard Configurations for Aeroelastic Applications of Transonic Unsteady Aerodynamics: AGARD Advisory Report 156, "AGARD Two-Dimensional Aeroelastic Configurations" and AGARD Advisory Report 167, "AGARD Three-Dimensional Aeroelastic Configurations."

Now that the AGARD has established standard aeroelastic configurations, the next effort is to encourage aeroelasticians in the NATO countries to develop improved methods of predicting transonic unsteady aerodynamics and aeroelastic response and to evaluate them with respect to the AGARD configurations. This Compendium assists that development and evaluation by collecting the known unsteady aerodynamic experimental data for the AGARD configurations. It is due mainly to the efforts of Mr Norman Lambourne, recently of the Royal Aeronautical Establishment, with Mr H C Garner of the RAE as a major collaborator.

The next phases will come under the guidance of facilitators for aeroelasticity:

France:	Mr R. Dat ONERA 29 Avenue de la Division LeClerc 92 Chatillon Paris
Germany:	Dr W. Geissler DFVLR-AVA Bunsenstrasse 10 3400 Gottingen
Netherlands:	Mr R. Zwaan NLR Anthony Fokkerweg 2 Amsterdam 1017
United Kingdom:	Mr H C Garner RAE Farnborough, Hants GU14 6TD
United States:	Dr J. Edwards NASA Langley Research Center MS 340 Hampton VA 23665

These facilitators will encourage contributions and communications among investigators in the NATO countries for a few key two-dimensional and three-dimensional standard configurations. They will present progress reports to the AGARD Structures and Materials Panel (SMP) in the Autumn of 1983. The effort will culminate in a Specialists' Meeting on "Transonic Unsteady Aerodynamics and Aeroelastic Application" at the SMP meeting in Fall 84. We encourage scientists in the NATO countries to communicate with one of the above facilitators to coordinate their contributions.

J. Olsen
AMES J. OLSEN
Chairman
AGARD/SMP Subcommittee on Aeroelasticity

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COMPENDIUM OF UNSTEADY AERODYNAMIC MEASUREMENTS

SUMMARY

The Compendium contains a selection of wind-tunnel measurements made on some of the AGARD Aeroelastic Configurations already chosen as computational test cases. Presentation of the numerical data in the form of separate Data Sets is preceded by a general review that discusses the various aspects concerning experimental measurements and comparisons with theoretical computations.

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Further Data Sets may be issued later, as addenda, when experimental results for other configurations become available.

Note: Although the General Review and the Data Sets are separate contributions, a consistent scheme of numbering the pages, references, tables and figures is used throughout the Compendium. Thus, for instance Table m.n is the nth table of Data Set m. For the General Review m = 0.

GENERAL REVIEW

by

N. C. Lambourne*

1 INTRODUCTION

Interest in the kind of unsteady aerodynamics considered here arises from the need for information relevant to the aeroelastic stability of aircraft. The continuing need for studies is due to design developments extending to different types of flow and to new structural configurations. At present there is special interest in transonic and separated flows, in wings specially designed for supercritical flow, and in surfaces operating as part of active control systems.

Advances in computational fluid dynamics are giving impetus to the development of new theoretical methods for unsteady aerodynamics. The development of satisfactory methods, whilst depending ultimately on comparisons with experiment, is considerably helped by comparisons between one computational method and another. To assist these developments a Working Group of the AGARD Structures and Materials Panel has already chosen a series of 2-D and 3-D configurations and for each a set of test cases, including a priority subset, to be used for comparisons. These test cases are fully identified in Refs 0.1 and 0.2, which are the documents that have set the scene for the present Compendium. The chosen configurations are known as the AGARD Aeroelastic Configurations and it is now convenient to denote the chosen cases associated with them as the Computational Test (or CT) Cases.

Although some of the configurations and some of the CT Cases were chosen purely for theoretical interest and do not have experimental counterparts, others were chosen because they had been, or were shortly to be, the subject of unsteady measurements. For the most part, these measurements had been made independently by various researchers and the resulting data are situated at separate locations or in diverse documents. The present Compendium was conceived with the idea of collecting into a single document the experimental data most important for the proposed comparisons.

Whilst the prime purpose is the presentation of numerical data, it seemed desirable to include information about the experiments themselves and to mention their more important results. Also, when experimental data are to be used for numerical comparisons, some indication of their reliability is needed; for this reason a general discussion of the various experimental procedures and the limitations of experimental data is included.

For the presentation of the material, it has been found convenient to follow the kind of arrangement already used in an AGARD document, Ref 0.3, giving a data base for steady aerodynamics.

2 GUIDE TO COMPENDIUM

The complete list of AGARD Aeroelastic Configurations is given in Table 0.1. For those configurations having Data Sets in this Compendium this table also gives the CT Case numbers (as defined in Refs 0.1 and 0.2) for which there are experimental data. For those configurations not having Data Sets the present position regarding the experiments is stated. It is intended to issue further Data Sets whenever possible.

The Compendium consists of a General Review, of which this present section is part, followed by seven self-contained Data Sets. Each Data Set provides:

- means for identifying and locating all the unsteady measurements that could be made available;
- a brief overview of the salient features of the experimental results;
- numerical data from those tests that relate directly to the CT Cases.

Also, by means of a standard form, each Data Set gives key information about the test equipment and test conditions - information that may be found important when comparing experimental and theoretical results.

It is hoped that the information contained in the Data Sets will satisfy the theoretician through the first stages of comparing calculation with experiment. At some later stage the need may arise for comparisons with experimental cases beyond those selected to correspond with the CT Cases. It is for that reason that each Set lists all the experimental tests for which data could be made available if requested from the original source.

The tables presenting the numerical data are mostly copies of computer listings from the original data banks. Therefore the forms and notations differ across the various Data Sets. To have reformatte the data to a standard notation and lay-out would

* Preparation of the Review and editing of the Compendium was funded by US Air Force Office of Scientific Research, European Office of Aerospace Research and Development.

have required much labour and incurred the risk of introducing errors - apart from which, a familiarity gained with the original form makes for easy communication if similar data are required for additional cases.

It will be seen from Table 0.1 that the present Data Sets extend over a range of 2-D section shapes and 3-D planforms. The unsteady model motions are basically either some form of rigid-body pitching or control-surface rotation; they are mostly small-amplitude oscillations, although Data Set 3 includes large-amplitude oscillatory and transient motions. The experimental cases also include a variety of types of subsonic and transonic flow, but it is necessary to refer to the Data Sets themselves for detailed specifications.

It may be noted that not every CT Case has an experimental counterpart.

2.1 Correspondence between experimental and computational cases

Although it is true that the related CT Cases were chosen from the available experimental tests, the degree of relationship between them differs over the complete series.

The type of unsteady motion is basically the same for corresponding experimental and computation cases. In some CT Cases the specification of parameters such as amplitude, frequency, Mach number, Reynolds number, model incidence and flap angle are in exact agreement with the experiments. But for Data Sets 4 and 5, which both relate to the super-critical aerofoil NLR 7301, there are differences between the experimental and CT values of model mean incidence α_m and Mach number M as shown in Table 0.2.

With regard to Data Set 4, the explanation is straightforward. The airfoil was designed by a hodograph theory which predicted shock-free flow at $M = 0.721$ and $\alpha_m = -0.19$ deg. In the NLR experiments this type of flow did not occur for those theoretical values of M and α_m but was approximated as closely as possible for a different combination: $M = 0.744$ and $\alpha_m = 0.85$ deg. The differences were mainly due to viscous effects and tunnel interference. Thus the CT specifications were chosen such that theory would produce flows similar to those observed in the experiments, on the argument that these specifications will compensate for the two effects.

The situation with regard to Data Set 5 is rather more complicated because, at the time the CT Cases were chosen, these data, generated at NASA Ames, were not available. As in the NLR tests, the experiments from which the data are abstracted were run for combinations of M and α_m which gave classes of steady flow corresponding to those predicted by the aerofoil design theory using the CT specifications. Thus the cases of Data Set 5 can be related to the CT Cases on the basis of similar flows but for this Set the values of the frequency parameters do not match the CT Cases exactly.

Data Sets 4 and 5 form a unique combination in providing independent measurements of comparable data for the same aerofoil. However, as shown in Table 0.2 there are differences between the Reynolds numbers for the two sets and also differences in regard to the use of boundary-layer transition trips. In addition there is an appreciable difference between the two ratios of tunnel to model size, which as discussed later, may be important in connection with the effects of tunnel interference. Examples of comparisons between these two Data Sets are discussed in section 7.

Certain implications arising from the differences between the experimental and CT specifications will be discussed later in section 8.

3 GENERAL NATURE OF UNSTEADY DATA

The practical requirement is for aerodynamic information for lifting surfaces and control surfaces undergoing arbitrary time-dependent displacements or deformations. Basic studies are usually centred on 2-D or 3-D model configurations performing prescribed unsteady motions in a uniform stream with steady perturbations.

In considering the general forms of the aerodynamic quantities it is convenient to restrict the discussion to pressures, the quantities that are measured. Since it is the distribution of pressure that determines the resultant forces and moments it will be readily appreciated that similar remarks can apply to quantities such as lift, pitching moment and control-surface hinge-moment. For the time being discussion will be concerned with pressure denoted by p , the introduction of non-dimensional coefficients being left until later.

For a given model configuration in a given flow, interest lies in the pressure distributions associated with an unsteady change in a model displacement parameter ϕ , which is a general coordinate to denote angle of pitch, control-surface deflection or some other quantity defining the unsteady motion. The basic problem is to determine $p(t)$ for the prescribed time-wise variation $\phi(t)$.

Experiments are sometimes made with non-harmonic forms of $\phi(t)$, and indeed Data Set 3 includes tests in which incidence is increased approximately linearly with time, but most unsteady experiments have been made for oscillatory conditions. Although there are special interests in large-amplitude motions, the main concern is with small

perturbations and the most usual form of testing is with small-amplitude continuous harmonic oscillations. For this reason it is the pressure quantities relating to harmonic oscillations that will now be discussed.

We consider a rigid model undergoing oscillatory pitching motion. In addition to specifying Mach number and Reynolds number, the condition of the model is defined by

- a mean condition about which the oscillation occurs, specified by a mean incidence α_m ;
- an oscillatory motion specified by the sinusoid $\phi = \phi_0 \sin \omega t$.

Associated with this oscillatory condition will be the following classes of pressure quantity:

- steady pressure for the steady mean condition;
- unsteady pressure for the oscillatory condition: this includes a mean and an oscillatory component;
- steady pressures resulting from steady model positions which correspond to successive instantaneous positions during the unsteady excursions.

When a system can be regarded as linear (*i.e.* p varying linearly with ϕ) there are just four kinds of pressure quantities to be determined:

- (1) steady pressure p_s for the steady mean condition identical with p_m the mean pressure during the oscillation;
- (2) in-phase component normalised by motion amplitude, p'/ϕ_0 ;
- (3) in-quadrature component normalised by motion amplitude, p''/ϕ_0 ;
- (4) steady pressure derivative, $dp/d\phi$.

As an alternative, a modulus and a phase angle can replace the in-phase and in-quadrature components.

The distribution of p_s characterizes the type of flow, which in many respects influences the oscillatory and derivative pressures. Components p'/ϕ_0 and p''/ϕ_0 are, in general, dependent on the frequency of oscillation, and their variations with frequency give an indication of the effects of unsteady aerodynamics. In a linear system the derivative $dp/d\phi$ is the zero-frequency equivalent of p'/ϕ_0 , and provides a useful datum from which the effects of unsteadiness can be assessed.

When non-linearities are present, the pressure variation can be expressed as the Fourier series:

$$p(t) = p_m + p' \sin \omega t + p'' \cos \omega t + p'_1 \sin 2\omega t + p''_1 \cos 2\omega t$$

plus higher harmonics. In the general non-linear case the Fourier coefficients are not necessarily proportional to the motion amplitude ϕ_0 , and the mean pressure p_m is not necessarily the same as the steady pressure p_s . Also the steady derivative $dp/d\phi$ needs to be replaced by another concept which will be discussed in the following section.

For attached flow serious non-linearities in pressure usually occur only for positions close to either a leading-edge, a flap hinge-line or a shockwave. Consequently being localised, the non-linearities tend to disappear when the pressures are integrated to give forces and moments. It is for this reason that even when non-linearity is present, practical interest continues to be centred on the fundamental components p'/ϕ_0 and p''/ϕ_0 . In most of the experiments included here, no attempt was made to measure any of the higher harmonics although large non-linearities were known to be occurring at a shockwave.

4 NOTATION

Various symbolic notations are used in the documents from which the information in the Data Sets has been obtained. Because the data listings are presented in their original form, it is necessary to explain the individual notations in each Data Set.

Some uniformity in notation is however desirable for future discussions and for this reason Bland, in Refs 0.1 and 0.2, has recommended a basic notation. This has been extended in this Compendium and, although the data listings retain their original forms, a move towards a standard notation has been made in preparing the diagrams and descriptive material for the Data Sets.

The following scheme is consistent with that proposed by Bland although there are a few minor changes. The sign conventions and some of the major definitions are shown in Fig 0.1 reproduced from Ref 0.2. The present scheme includes the basic notation and an extension to deal with the unsteady aerodynamic quantities.

BASIC NOTATION

Model geometry

local chord: c
 root chord: c_r
 model span: s
 full-span aspect ratio: AR
 sweepback angle: Λ
 taper ratio: $\lambda = \text{tip chord}/\text{root chord}$
 streamwise position aft of root leading edge: x
 chordwise position aft of local leading edge: ξc
 spanwise position: ηs
 local position of pitching axis: x_a
 local position of flap hinge: x_δ
 incidence: α
 flap angle: δ (measured in a streamwise section)

Stream

Mach number: M
 Reynolds number based on root chord: Re
 velocity: v
 static pressure: p_s
 total pressure: p_t
 dynamic pressure: q
 total temperature: T_0
 ratio of specific heats: γ

Model pressure (steady or instantaneous values)

surface pressure: p
 pressure coefficient: $C_p = (p - p_s)/q$
 pressure ratio: p/p_t
 pressure resultant loading: $\Delta C_p = (C_{p \text{ lower}} - C_{p \text{ upper}})$

Model surface flow

local Mach number M_L determined from a measured pressure ratio by the isentropic relation:

$$M_L = \left\{ \frac{2}{(\gamma - 1)} \left[\left(\frac{p}{p_t} \right)^{-(\gamma-1)/\gamma} - 1 \right] \right\}^{1/2}$$

Section force coefficients

$$\text{lift: } c_L = \int_0^1 \Delta C_p d(x/c)$$

$$\text{pitching moment: } c_m = \int_0^1 \Delta C_p (x_a/c - x/c) d(x/c)$$

(Note: This definition of c_m is more general than that in Fig 0.1 because it relates to the moment about point x_a which need not be the same as x_a about which the model is pitching.)

$$\text{flap lift: } c_{L\delta} = \int_{x_\delta/c}^1 \Delta C_p d(x/c)$$

Section force coefficients (concluded)

$$\text{flap hinge moment: } c_h = \int_{x_0/c}^1 \Delta C_p (x_0/c - x/c) d(x/c)$$

UNSTEADY NOTATION

Model motion

time: t

non-dimensional time: $\tau \equiv 2Vt/c$

general coordinate for model motion: ϕ

arbitrary motion: $\phi(t)$ or $\phi(\tau)$

oscillatory motion: $\phi = \phi_0 \sin \omega t$ (or $\phi_0 \cos \omega t$)

oscillatory amplitude: ϕ_0 representing a_0 , θ_0 or δ_0 (Data Set 7)

mean incidence during an oscillation: a_m

mean flap angle during an oscillation: δ_m

oscillation frequency: f (Hz), or $2\pi f = \omega$ (rad s⁻¹)

reduced frequency: $k = \omega c / 2V$, or $\omega c_x / 2V$

Unsteady pressures

For an arbitrary model motion $\phi = \phi(\tau)$, the time-wise variation of instantaneous pressure is defined as

$$c_p(\tau) = (p(\tau) - p_\infty) / q .$$

Oscillatory pressures

For the oscillatory motion $\phi = \phi_0 \sin \omega t$, a general equation for oscillatory pressure is

$$p(t) = p_m + p' \sin \omega t + p'' \cos \omega t + p'_1 \sin 2\omega t + p''_1 \cos 2\omega t + \text{etc}$$

or the alternative,

$$p(t) = p_m \pm [p_0 \sin(\omega t + \epsilon_0) + p_1 \sin(2\omega t + \epsilon_1) + \text{etc}] .$$

The sign outside the brackets in the last equation is a matter of choice. However, it is most convenient to choose the negative sign for the upper surface of the model and the positive for the lower, then usually the phase angles ϵ_0 in degrees for both surfaces will tend to zero, and not 180 deg, as the frequency tends to zero. Also this choice of signs is consistent with the usual method of plotting chordwise distributions of oscillatory pressure.

Mean pressure during oscillation: $C_{pm} = (p_m - p_\infty) / q$

Fundamental (1st harmonic) amplitude-normalised components

in-phase (or real component): $C_p'/\phi_0 = p'/q\phi_0$

in-quadrature (or imaginary component): $C_p''/\phi_0 = p''/q\phi_0$

Where an oscillatory quantity can be expressed as a complex amplitude a bar is used thus:

$$\text{complex amplitude: } \bar{C}_p/\phi_0 = (C_p'/\phi_0) + i(C_p''/\phi_0) = \pm (|\bar{C}_p|/\phi_0)e^{i\epsilon_0}$$

$$\text{modulus: } |\bar{C}_p|/\phi_0 = \left[(C_p'/\phi_0)^2 + (C_p''/\phi_0)^2 \right]^{1/2}$$

$$\text{phase angle: } \epsilon_0 = \tan^{-1}(C_p''/C_p') .$$

Following the recommendation of Ref 0.1 the motion normalised quantities defined above are represented by a combined symbol including the normalising amplitude ϕ_0 , which in particular cases will be replaced by a_0 , θ_0 or δ_0 . It should be noted that in some existing notations the normalising amplitude is omitted from the symbolic representation. Thus an existing notation may use C_p' and C_p'' respectively for the quantities C_p'/ϕ_0 and C_p''/ϕ_0 per radian as now proposed.

The $(n+1)$ th harmonic

in-phase component: $C'_{pn}/\phi_0 = p'_n/q\phi_0$

in-quadrature component: $C''_{pn}/\phi_0 = p''_n/q\phi_0$

complex amplitude: $\bar{C}_{pn}/\phi_0 = (C'_{pn}/\phi_0) + i(C''_{pn}/\phi_0) = \pm (|\bar{C}_{pn}|/\phi_0)e^{ie_n}$ with modulus $|\bar{C}_{pn}|/\phi_0$ and phase angle e_n .

Unsteady forces and moments

The sectional unsteady forces and moments are obtained from the pressures by integration of the separate in-phase and in-quadrature components. The amplitude normalised coefficients are represented symbolically by using c_l , c_m , c_h etc in place of C_p . Thus \bar{c}_l/ϕ_0 represents the normalised complex amplitude of lift.

Use of p_t rather than q as a non-dimensionalising factor

In the preceding notation, apart from pressure ratio p/p_t in the expression for local Mach number M_L , all the aerodynamic pressure and force quantities have been divided by q to make them non-dimensional. An alternative which, as will be discussed in section 8, has advantages in certain circumstances is to use p_t in place of q . Thus the complex pressure amplitude $\bar{p}/p_t\phi_0$ is an alternative to \bar{C}_p/ϕ_0 . Of course the two forms are related through the stream Mach number by the relation:

$$p_t/q = [1 + \frac{1}{4}(\gamma - 1)M^2]^{1/(\gamma-1)} / \frac{1}{4}\gamma M^2 .$$

Units

Incidence, control angle, amplitude of angular motion and phase angle are conventionally specified in degrees. Oscillatory pressure or force when normalised by an angular motion are usually specified 'per radian'. The amplitude of a linear motion is preferably made non-dimensional by dividing by a model dimension.

Quasi-steady and steady perturbation pressures

Several kinds of steady, or quasi-steady, quantities are used as equivalent quantities to provide comparisons with the unsteady ones; the application in the linear case of the steady quantity $dC_p/d\phi$ has already been mentioned. The following discussion is intended to clarify the distinctions between the various forms these quantities can take.

The term 'quasi-steady' is usually applied to all such quantities but for the identification of experimental data it would seem preferable for this term to be applied only to those quantities that are measured in the same way as unsteady quantities but for slow rates of change. Such a quasi-steady oscillation, denoted by $\dot{\phi} = 0$, would yield for each in-phase component a quasi-steady value, for instance $(C'_p/\phi_0)_{qs}$.

Data Sets 6 and 7 both include measurements for comparatively low-frequency oscillations which are regarded as quasi-steady.

The term 'steady perturbation pressure' is a better description of those quantities obtained by steady pressure measurements made for two or more stationary conditions of the model close to the mean condition. The simplest of these is an approximation to the derivative $dC_p/d\phi$ obtained from measured steady pressures C_{p+} and C_{p-} corresponding respectively to the two conditions $-\phi_1$ and $+\phi_1$. The quantity taken to be comparable with the unsteady in-phase component C'_p/ϕ_0 is then $\delta C_p/\phi_0 = (C_{p+} - C_{p-})/2\phi_1$ with the deflection ϕ_1 chosen to be the same as, or related to, the amplitude of oscillation ϕ_0 . Data Sets 1 and 4 contain data obtained in this manner.

More detailed information could be obtained if measurements are made for several increments of ϕ_1 so that the form of steady $C_p(\phi)$ over the oscillation amplitude is revealed. Then an average slope $dC_p/d\phi$ could be obtained, say, by 'least squares'.

To make allowance for non-linearities it is in principle possible to extend the measurements further so that they become equivalent to the steady quasi-oscillation $\phi = \phi_0 \sin \psi$, with $0 < \psi < \pi/2$. Provided the chosen values of ψ are sufficiently numerous, the measured steady pressures can be regarded as sampled data from which the fundamental and higher harmonic values can be calculated. In particular such measurements would yield a steady quantity $(C'_p/\phi_0)_s$ which is directly comparable with its unsteady counterpart C'_p/ϕ_0 . Although none of the present Data Sets contains quasi-oscillatory

quantities of this nature, it may be possible to derive such quantities from data available from the original sources.

In short, under the customary generic title 'quasi-steady', three of the possible kinds of quantity comparable with the unsteady C_p'/Φ_0 are:

- (1) Low-frequency equivalent $(C_p'/\Phi_0)_{qs}$ measured for $k \rightarrow 0$;
- (2) Steady derivative $\delta C_p'/\delta\Phi$, or $dC_p'/d\Phi$;
- (3) Steady quasi-oscillatory quantity $(C_p'/\Phi_0)_s$.

In many cases a low-frequency change will become equivalent to a series of steady conditions as the rate of change is reduced. But there are special circumstances where this is not so - where even the slowest rate of change includes an unsteady event. Such a situation occurs when the motion, however slow, leads to the onset of flow separation where the actual process of shedding vorticity occupies a period of time largely independent of the rate of change. That is the condition $k \rightarrow 0$ is not always the same as the condition $k = 0$.

In addition to the fundamental differences in the form of these three quantities it may be necessary to take into account the differences between the method used to measure (1) and that used to measure the steady pressures from which (2) and (3) are derived. Sometimes different instrumentation is employed to obtain unsteady and steady measurements, in which case also, the unsteady and steady measuring positions may not be the same. Thus, whilst $(C_p'/\Phi_0)_{qs}$ and the unsteady C_p'/Φ_0 are obtained with the same instrumentation, a comparison between C_p'/Φ_0 and a steady perturbation quantity may involve different measuring systems and different accuracies.

5 EXPERIMENTAL PROCEDURES AND INTERPRETATION OF RESULTS

The intention here is to give a brief account of some of the procedures commonly adopted in the experimental measurements and, by so doing, to draw attention to the possible limitations of the data. It is also hoped that this account will lead to an appreciation of the significance of the details of the test equipment and test conditions that are given in a standard form in each Data Set. A more extensive account of experimental techniques used in unsteady aerodynamics is contained in Ref 0.4.

Each series of tests involves a model, equipment to provide the required unsteady motion, instrumentation to measure the model motion and pressure distributions, and a wind tunnel to provide the appropriate test conditions.

The characteristics of the tunnel and the interference effects produced are of especial importance and form the subject of section 6.

5.1 Model motion

In each of the present experiments the model was designed to perform rigid-body motion. All the 2-D aerofoil models (Data Sets 1 to 5) were stiff enough to be regarded as rigid, but for the half-models of Data Sets 6 and 7, flexibility led to the basic applied motion being augmented by a small amount of elastic distortion dependent on oscillation frequency and aerodynamic loading.

The model motion, even when elastic deformation occurs, is usually defined by the output of a displacement transducer arranged to measure the motion reference coordinate Φ , and to provide a time-varying electrical signal which is used as a phase reference for harmonic analysis. When the model cannot be regarded as rigid, some assessment of the actual motion which includes the unsteady deformation may be obtained from a distribution of accelerometers installed inside the model. By this means the true motion can be related to the measurements of Φ .

5.2 Measurement of pressure

There are various schemes for measuring surface pressures. All of them depend on one or more pressure transducers to provide electrical outputs which are the actual quantities that are processed and eventually measured. Sometimes, as in Data Sets 2, 5, 6 and 7, two different systems are used in the same experiment: one to measure pressures in the steady state, the other for measurements in unsteady conditions. Then the steady and unsteady distributions may not be measured for the same positions, as in Data Sets 6, 7. One type of unsteady measuring system uses small transducers installed within the model and connected to orifices at the model surface. But in another system, as used for Data Sets 1 and 4, unsteady pressures are piped to a location outside the tunnel and switched in sequence to a single transducer. With any system the measurement that is sought is the surface pressure which would be acting at the position of the orifice: what is actually measured is the pressure acting at the diaphragm of the transducer. Therefore, unless the transducer is actually part of the surface there is always a question about the transfer function between the pressure acting at the orifice and that at the transducer. In systems where the unsteady pressures are piped to a distant measuring device, the determination of these transfer functions is a vital part of the calibration. When the transducer is situated very close to the orifice and the enclosed volume of air is small, the effects of transmission are usually neglected. However, a feature, which is common

to all systems and very difficult to simulate in bench calibrations, is the effect of the flow across the orifice.

Whether or not the transfer function between orifice and transducer diaphragm is significant, the calibration factor relating the unsteady electrical output to unsteady pressure is of paramount importance. Whereas good standards of steady pressure are commonplace, there is no readily available definitive standard for oscillatory pressure. Although the experimenters will have taken great care over this matter, it is easily appreciated that a systematic error in the calibration could lead to undisclosed errors in all the measurements of a series.

5.2 Signal processing

In oscillatory tests, the electrical signals from the pressure transducers are usually processed in some manner to yield harmonic components phase-referenced to the signal representing the motion coordinate ϕ . However this is not so for Data Set 3 in which the pressure and motion signals are sampled to provide instantaneous values at a series of known time-intervals.

It is unnecessary to describe in detail the methods of processing the electrical signals, but it is important to be aware of the nature of the signals and to understand the kind of quantities that result from the processing. Almost inevitably the signal from a transducer sensing an aerodynamic pressure includes, in addition to the wanted signal, random-like fluctuations from various sources. Transonic tunnels with their slotted or perforated walls are prone to produce stream flows with some degree of inherent unsteadiness. Model flows which are supercritical, or separated, may themselves provide another source of unsteady disturbance. Thus even when the model is stationary the pressure signals may include fluctuations. When the model is undergoing a prescribed unsteady motion the complete pressure signal will represent a combination of random fluctuations and the response to the motion.

Depending on the type of signal processing employed, the result could be

- an instantaneous value;
- a time-average;
- a cycle-average of instantaneous samples taken at corresponding times in a number of cycles;
- a series of harmonic components obtained by Fourier analysis over either a whole number of cycles or a certain period of time.

Steady pressures are usually measured as averages over short periods of time. In general, time or cycle averaging is beneficial in reducing, if not always eliminating, the effect of random fluctuations. In some circumstances, where the unsteady process under investigation itself includes some form of randomness, averaging can obscure features of the individual cycles. Because the experiments from which Data Set 3 was extracted included an element of randomness in each cyclic onset of flow separation, both quasi-steady and unsteady pressures were measured as instantaneous values.

5.3 Occurrence and effects of extraneous fluctuations

When extraneous pressure fluctuations, independent of the applied model motion, are produced by an instability of the flow over the model they are a proper feature of the flow phenomenon and as such should appear in the results and require theoretical modelling. It is for this reason that items 5.11 or 5.12 of the test specification have been requested in each Data Set.

When the fluctuations are the result of turbulence or other unsteadiness in the tunnel flow it is desirable for their effects to be reduced by averaging. Whether they can be completely eliminated by averaging depends on whether they are linearly superposed on the pressure response to the prescribed motion or whether there is some form of non-linear interaction. In highly non-linear situations in the close vicinity of a shockwave, extraneous fluctuations can lead to erroneous data. Examples of such interference are mentioned in Refs 0.4 and 0.5.

5.4 Non-linearities

For small excursions away from the mean condition the pressure over much of the model surface will vary linearly with steady displacement ϕ . Exceptions to this become evident when measurements are made near to a leading edge or a control-surface hinge-line, or close to a shockwave. Non-linearities in the steady pressure variation are accompanied by the presence of higher harmonic components under oscillatory conditions; the manner in which these are produced in the close neighbourhood of a shockwave has been described in Refs 0.6 and 0.7.

Measurements of harmonic components are often limited to the fundamental on the grounds that this is the only component of importance in practical problems of aero-elasticity. Only Data Set 4 includes any numerical data for higher harmonics although Fig 6.6 of Data Set 6 gives graphical information on the spectral content of the pressures for transonic flow. Also Data Sets 2 and 5 include instantaneous pressures over a cycle of oscillation, which show non-linear features.

If in some circumstances the presence of higher harmonics in the oscillatory pressures is found to be independent of chordwise position, it is advisable before attributing these to non-linear aerodynamics to verify that the model motion is truly simple harmonic. This comment is relevant to any Fourier analysis that might be made on the instantaneous data presented in Data Set 3 which gives information on the harmonic distortion in the model motion.

When non-linearity is present, the values of the amplitude-normalised quantities C'_p/ϕ_0 and C''_p/ϕ_0 and the steady quantity $\delta C_p/\delta\phi$ are liable to be dependent on the displacement amplitude. This point needs to be borne in mind before placing too much emphasis on the peak values of these quantities obtained at the position of a shockwave. Interesting examples of amplitude dependence are shown in Fig 2.3 of Data Set 2 and Fig 5.7 of Data Set 5.

Irregularities in the chordwise distribution of the oscillatory pressure components are sometimes found near to the leading edge. These may be due to non-linearities associated with a local separation or with the disturbance produced by a transition-trip. Such irregularities usually appear only for small amplitudes, and disappear when the amplitude is increased.

To summarize, indications of non-linearity include:

- non-linearity in $C_p(\phi)$;
- amplitude effects on the fundamental components C'_p/ϕ_0 and C''_p/ϕ_0 ;
- non-sinusoidal time histories;
- higher harmonic components from Fourier analysis;
- irregularities in chordwise distributions of the oscillatory components.

5.5 Reduced frequency

The exact values of the test frequencies are often chosen for practical reasons such as the need to avoid unwanted resonances of the model or its supports. Almost invariably, tests are made for sets of fixed frequencies of oscillation so that for each constant frequency the reduced frequency k , varies with Mach number M and stream total temperature T_0 . For a fixed M , k varies inversely with $\sqrt{T_0(K)}$. Total temperature in a tunnel is not always closely controlled so that the value of k can vary during a tunnel run, but even in an extreme case where temperature changes from 25°C to 35°C the value of k would change by only 2%. Such a change is hardly likely to have a serious effect on the unsteady aerodynamics.

No uniform procedure has been adopted in specifying the test values of k . When either an average or a nominal value is quoted for each combination of M and f , it will be appreciated that the true value may differ by a few percent.

Tests made with substantially different values of frequency are included in most series of measurements. For rigid models the interpretation of the results is straightforward, but if model flexibility is significant, care has to be taken to eliminate any effects of changes in the oscillation mode with frequency.

5.6 Mach number and model incidence

These are the main parameters that define the basic flow from which the unsteady changes are made. In some cases the actual incidences and tunnel Mach numbers may be found to be slightly different from the specified nominal values.

For models with symmetrical sections, the datum incidence $\alpha = 0$ is usually set to align with the known flow direction of the tunnel. For models having sections that are not symmetrical the method of setting incidence is given in item 5.7 or 5.9 of the specification in each Data Set.

Where measurements of tunnel Mach number and model incidence are subject to standard corrections for wall interference, the details are given in item 9.6 of each specification.

5.7 Tunnel pressure and Reynolds number variations

The Reynolds number for a test depends on the pressure and temperature of the flow in the tunnel. Usually flow temperature is not closely controlled so that there may be small variations in Reynolds number throughout a series of tests. For those test series where tunnel total pressure remains constant, the Reynolds number is different for each Mach number. In tunnels where total pressure can be changed, variation of this quantity provides a means of obtaining data over a range of Reynolds number for each Mach number.

But as well as changing Reynolds number, alteration of total pressure can produce side-effects which, unless recognised and taken into account, may lead to apparent trends with Reynolds number that are in fact spurious.

For instance, an increase in total pressure means an increase in all the unsteady pressures, with a consequent improvement in the measurement accuracy. This in turn may mean a reduction in random errors and result in smoother pressure distributions. Also a change in total pressure alters the mean pressure level at which the transducers are operating and, in the presence of non-linearity, this can lead to a change of transducer sensitivity factor. If not accounted for in the calibration this could appear as a spurious Reynolds number effect.

An increase in the aerodynamic loading on the model is also produced by increasing the total pressure, and if the flexibility of the model is significant, this can lead to distortion of the model and to modifications to the mode of oscillatory motion. Data Sets 2 and 5 include data for a range of Reynolds numbers, but for these there is no possibility of unwanted aeroelastic effects because of the rigidity of the 2-D models.

5.8 Transition fixing and Reynolds number

Most of the tests were made for Reynolds numbers less than full-scale. To avoid unwanted effects associated with laminar boundary layers, trips to fix the transition position were fitted to some of the models. No trips were fitted for the measurements of Data Set 3 because the Reynolds numbers of the tests matched those of the full-scale helicopter blades to which the experiments were directed. Data Sets 1, 6 and 7 present numerical data for only models with transition trips, whilst for the experiments of Data Sets 2 and 5 no trips were attached. Data Set 4 gives information about the effects of fixing transition; in this Set transition was fixed for some cases and for others it was free. Data Set 6 contains a brief discussion of transition fixing in terms of increasing the thickness of the boundary layer, and provides graphical information about the effect this has on the unsteady loading produced by an oscillating control surface.

Data Sets 4 and 5 which give measurements for models having the same aerofoil shape, offer comparisons, as already shown in Table 0.2, between (a) tests with transition fixed at comparatively low Reynolds number, and (b) tests with free transition for a range of Reynolds number. Some of these comparisons will be discussed in section 7.

The desirability of fixing transition and the best position in the chord for attaching the trips are debatable matters. On the one hand if transition remains free, a laminar boundary layer may lead to types of flow separation and shockwave boundary-layer interactions that are unrepresentative of full-scale. Also it is possible that, when natural transition is delayed to a rearward position of the chord, the cyclic excursions of the transition point due to a model oscillation may engender non-typical oscillatory pressures of no practical interest. On the other hand when transition trips are used, the turbulent boundary so produced is usually too thick over the rearward part of the chord, thus over-emphasizing viscous effects which can be especially serious for a trailing-edge control, see Fig 6.4.

With regard to tests with over-thick boundary layers, Binion, Ref 0.8, points out that with modern designs of wings, even at high Reynolds number, viscous effects are likely to be so large that worthwhile calculation methods must be able to take these effects into account. The conclusion then is, albeit for steady conditions, that provided the class of flow is representative, tests with thick boundary layers do provide a useful challenge to theoretical computations. The objective of fixing transition therefore depends to some extent on whether the experiments are aimed at providing data appropriate to full-scale Reynolds numbers, or providing data to validate viscous calculations.

5.9 Accuracy of measurements

The accuracy with which the relevant quantities are measured is clearly an important matter although, as will be discussed in subsequent sections, the quality and reliability of experimental data involve wider considerations concerning the test environments.

It may be taken for granted that steady pressure, Mach number, incidence, steady deflections and oscillation frequency are measured with adequate accuracy. It is the accuracies of unsteady pressure quantities such as C_p'/ρ_0 and C_a'/ρ_0 that give cause for concern. Each of these quantities is derived from separate measurements of small changes in pressure and small displacements of the model. The measurements are made with instrumentation operating under dynamic, not steady conditions, and their accuracy depends crucially on the calibration procedure. It is easily seen that a systematic error in the measurement of a pressure harmonic component, or of a motion amplitude, could affect the whole set of measurements.

Whereas the resolution of the instrumentation or the day-to-day repeatability, both of which set limits to the accuracy, are fairly easy to determine, the overall accuracy of a measurement is extremely difficult to quantify. Usually the most that can be expected is a statement to the effect that the measurement of quantity A is no better than x percent. Such statements are usually made on personal, and to some extent intuitive, assessments based on the experience of the experimenter. To demand more would be unreasonable, for a thorough analysis of possible errors could easily entail as much work as the measurements themselves.

6 TUNNEL INTERFERENCE

All measurements obtained from wind tunnels are liable to suffer from the effects of tunnel interference. That is, the data obtained may differ from those which would be obtained with the same model moving in a free and uniform atmosphere. With that as a broad definition, the various sources of interference are:

- (1) Wall constraint on the flow.
- (2) Shockwave reflections from the walls.
- (3) Side-wall boundary layers in 2-D tests.
- (4) Reflection-plane boundary layer in half-model tests.
- (5) Support interference in complete model tests.
- (6) Flow fluctuations inherent in the tunnel flow.
- (7) Curtailment of wake vorticity by tunnel corner, shockwave or fan.
- (8) Reflection of acoustic disturbances at the walls.
- (9) Occurrence of tunnel resonance.
- (10) Acoustic disturbances propagated through a plenum chamber.

Items (1) to (6) affect both steady and unsteady measurements, whereas items (7) to (10) are peculiar to unsteady conditions. General accounts of the effects of interference on unsteady measurements are given in Refs 0.4 and 0.5. Of all the possible causes of interference, the only ones likely to be important to the present data are the constraint and reflection properties of the walls (items (1), (2) and (8)) and, if flow separation occurs at the model, the effects of the side-wall and reflection-plane boundary layers (items (3) and (4)). Tunnel resonance is known to be possible in 2-D tests (Ref 0.9) but no occurrences are reported in any of the Data Sets.

Because of its more complicated nature, interference on unsteady measurements is poorly understood in comparison with interference on steady measurements. Since some part of the total effect on an unsteady measurement can be attributed to steady interference - indeed for supercritical conditions the steady effect may be the major contribution - it is important to clarify the distinction and see how much of the total effect can be accounted for by steady considerations.

Consider for the moment a specific event in which a model initially at a steady incidence α_A is rapidly moved to a new steady incidence α_B . After sufficient time has elapsed we can assume that the flow has reached a new steady state appropriate to the new steady incidence. If the event occurs in a wind tunnel, the initial flow for α_A and the final flow for α_B are both subject to steady interference. The manner in which the flow changes with time, and indeed the time taken for the flow to approach its final steady state are subject to unsteady interference. The totality of the interference on the unsteady event is a combination of these steady and unsteady contributions.

For the more usual type of unsteady test where the model is given an oscillation of small amplitude ϕ_0 about a mean incidence α_m and conditions are linear, the aerodynamic pressure characteristics are fully described by

- (1) C_p for steady α_m .
- (2) $(|\bar{C}_p|/\phi_0)_{qs}$, the amplitude for a quasi-steady oscillation identical with $dC_p/d\phi$.
- (3) Variations with frequency of amplitude $|\bar{C}_p|/\phi_0$ and phase angle ϵ_0 .

Quantities (1) and (2) are affected by only steady interference and provided these effects can be accounted for, the only unsteady effects are those concerning the phase angle and variations with frequency, (3).

A crucial question is whether the aerodynamic measurements can be corrected for the interference effects. For supercritical flows simple forms of correction are generally impossible, but it is still helpful to approach the question from the standpoint of purely subsonic flow. Classical theory for steady subsonic flow regards wall constraint as consisting, in effect, of incremental changes in

- stream velocity due to blockage;
- model incidence due to induced upwash;
- lift and pitching moment due to streamline curvature.

On this simple basis, which neglects buoyancy effects due to the streamwise gradient of blockage, the condition of a model in a tunnel can be regarded as equivalent to the

condition in free air of another model with a different camber set at a different incidence in a stream of modified velocity. For subsonic conditions values of the incremental changes can be obtained by theoretical calculations if the boundary conditions at the walls can be mathematically defined or if the wall pressures are known, or possibly by empirical means if the wall conditions are unknown.

The concept of an equivalent free-air system suggests, if the effects of streamline curvature are simplified, that the steady part of the wall constraint affecting oscillatory measurements might be equivalent to changes in stream Mach number and mean incidence. This leads to a possible basis for making comparisons between theory and experiment which will be discussed later in section 8.

For the oscillatory type of test mentioned previously a possible correction procedure would consist of applying corrections to:

- (1) M and a_m - to account for steady interference on the mean condition;
- (2) $(|\bar{C}_p|/\phi_0)_{qs}$ - to account for steady interference on the quasi-steady perturbation;
- (3) $|\bar{C}_p|/\phi_0$ and ϵ_0 - to account for the unsteady interference.

The procedure is illustrated schematically in Fig 0.2 which shows a hypothetical variation of $|\bar{C}_p|/\phi_0$ and ϵ_0 with reduced frequency k . It is assumed that the measured steady C_p obtained for the steady condition (M, a_m) would be obtained in free air for another steady condition $(M, a_m)'$. The curves labelled 1 are those measured in the tunnel for (M, a_m) ; those labelled 2 would be obtained in free air for the mean condition $(M, a_m)'$. Steady interference is responsible for the displacement Δ_1 . If curve 1A is drawn parallel to curve 1; or more strictly to give Δ_1 proportional to the modulus of total lift, then the additional and unsteady interference effects are represented by Δ_2 and Δ_3 . Ability to apply corrections to the measurements requires knowledge of the translation from (M, a_m) to $(M, a_m)'$ and the values of Δ_1 , Δ_2 and Δ_3 .

For subsonic conditions, corrections to M and a_m and corrections of the type Δ_1 applicable to lift and moment may be obtained theoretically or empirically. In principle, corrections of types Δ_2 and Δ_3 could be obtained from the extensions of classical interference theory to unsteady conditions, as described in Ref 0.10. But, as for the steady corrections, the calculations depend on an adequate definition of the wall boundary conditions which, for the unsteady case, includes time dependence.*

For the present data, any purely theoretical forms of interference corrections are liable to be unreliable because of inadequate definition of boundary conditions for the ventilated walls of the tunnels in which the data were obtained.

Broadly speaking, the steady constraint effects in a ventilated tunnel depend on the degree of ventilation; in principle at least, careful matching of the wall geometry and wall porosity to the model geometry could result in negligible interference (see for instance Ref 0.11). More usually, the measured slope of the steady lift curve for a particular model will be too large or too small depending on whether the tunnel walls are 'too closed' or 'too open'. Also it is to be expected that the larger the model is relative to the tunnel, the greater is the influence of wall constraint.

Even if the wall boundary conditions can be adequately defined, theoretical corrections to the measurements are simply not possible for supercritical flow conditions. A useful discussion of steady interference under transonic conditions is given by Binion, Ref 0.8. He points out that, where the supercritical region is no longer small with respect to the tunnel dimensions, the effect of wall constraint can no longer be regarded in the classical terms of blockage, upwash and streamline curvature; instead it must be regarded as a complicated distortion of the flow field which can strongly influence the shockwave and separation patterns. In which case, there may no longer be an equivalent free-air condition corresponding to the model in the tunnel.

It is unfortunate that the foregoing discussion has done little except describe the difficulties of making corrections to the measured unsteady data.

In none of the Data Sets are any corrections made for unsteady interference but in some Sets, steady-based corrections are either made, or the method for applying them is described. In Data Set 4, although the presented data include no interference corrections whatsoever, formulae are given for making corrections to the incidence, and to the lift and moment for steady conditions. In Data Sets 4 and 5, as already explained in section 2.1, some adjustments have been made between the experimental values of M and a_m and those chosen for the CT Cases; to some extent these adjustments are intended to account for the steady interference effects.

* Addendum: The author's attention has been drawn to recent methods of including the effect of the walls in unsteady calculations for aerofoils and controls (see Refs 0.13, 0.14).

Data Set 5 comprises results obtained with a model having the same basic shape as the model of Data Set 4 - two examples of comparisons between the two sets will be discussed in section 7. In making other comparisons between the two Sets it should be noted that, in addition to the differences shown in Table 0.2, the ratios of tunnel height to model chord are 3.1 for Data Set 4 and 6.7 for Data Set 5. However, because of the beneficial effect of wall ventilation, which to some unknown degree applies to both tunnels, it cannot without further analysis be concluded that the interference effects on Data Set 4 are necessarily larger than those on Data Set 5.

In Data Set 3 where the unsteady data are presented as instantaneous values of C_p and sectional force coefficients for instantaneous values of incidence α , the tabulated values of the incidence and the force coefficients, but not C_p , have been corrected for tunnel constraint as if each instantaneous value were obtained for a steady condition.

Data Set 7 is unique in being abstracted from an investigation into tunnel interference. In the light of the evidence obtained from several tunnels it is believed that the data for the two largest tunnels are free from any large effects due to tunnel constraint interference.

7 UNCERTAINTIES OF EXPERIMENTAL DATA

If experimental results are used only as qualitative information questions of accuracy and reliability hardly arise. But when making quantitative comparisons the user of experimental data will certainly want to know the confidence that can be placed on the measured values. Basically the question is how well do the measured unsteady aerodynamic quantities relate to the specified configuration, its motion, and to the test conditions defined by parameters such as M , Re , a_m and k . The answer is seldom straightforward. It depends not only on the accuracy of the measurements and the manufacturing accuracy of the physical model but also on the appropriateness of the wind-tunnel test conditions and the uncertainties of wind-tunnel interference. In critical situations in the presence of shockwaves or separations the answer also requires knowledge of the sensitivity of the measured data to small changes in the parameters.

A general insight into the uncertainties of measurements and an idea of the confidence that can be placed in experimental data can be obtained from a comparison of results obtained in different ways. For instance, confidence in the technique of unsteady pressure measurement was obtained when, on several occasions in the past, different organisations made comparative measurements using their own forms of instrumentation. Usually, however, such comparisons are not completely independent because they use either the same model, or the same tunnel, or both.

Examples of comparisons obtained with the same model in two different tunnels, thus providing evidence of the effects of tunnel interference, are given by Figs 7.20 and 7.21 of Data Set 7. In these comparisons the model was small in relation to the sizes of the tunnels; unfortunately the confidence gained by these comparisons does not necessarily apply to every other situation. In the same Data Set, Figs 7.16 to 7.19, also provide evidence of the sensitivity of the measured oscillatory pressures to small changes of M and a_m for some examples of transonic flow.

The two investigations from which Data Sets 4 and 5 are drawn provide a rare opportunity for comparing two independent sets of measurements. The data available for comparison relate to oscillatory pitching of the NLR 7301 supercritical airfoil. It is important to note that the two sets were obtained with different physical models in different wind tunnels by different experimenters using different instrumentation. As such the two experiments were completely independent.

At the outset, before making comparisons of the measured data, there are three points to be noted: firstly, there are differences in the degree to which each physical model represents the design shape of the NLR 7301 aerofoil; secondly, in neither case has there been any attempt to apply tunnel interference corrections to the measured unsteady data; and thirdly, there are no exact correspondences between the parametric conditions of the two tests.

Fig 0.3 provides comparisons between the measured and the design ordinates for a portion of the upper surface of each physical model. The ordinates for the NLR physical model are taken from Tables 4.1 and 4.2 of the present document; those for the Ames model are taken from Ref 5.4 which mentions that, owing to an expansion of the manufacturing mould, the model is slightly thicker than it should be. The same report also contains a suggestion, which is supported by Fig 0.3, that the surface of the model is not as smooth as the design shape.

Two examples of data comparisons will now be discussed. Not only do they provide evidence of the kind of uncertainties surrounding experimental data, but they provide a foretaste of situations requiring judgements to be made when comparing calculated and experimental results. In each example the unsteady quantities being compared are the distributions of the oscillatory pressure components, C'/a_0 and C''/a_0 , for the upper surface only. The different tests are identified by the NLR Run No. or the Ames Dynamic Index.

The first example, chosen because of the aerodynamic simplicity of purely subsonic flow for $M = 0.5$, relates to CT Case 2. The three tests being compared are identified:

Test	M	α_m (deg)	α_0 (deg)	k	$Re \times 10^{-6}$	Transition
NLR 1301	0.498	0.85	0.4	0.26	1.7	Fixed at 0.3c
Ames 185	0.508	0.58	0.5	0.20	2.3	Free
Ames 170	0.508	0.58	0.5	0.20	9.3	Free

The steady pressure distributions are shown in Fig 0.4a. Whilst examining these it may be noted that there is adequate agreement between the test Mach numbers and that, because the flow is subsonic, no great significance need be attached to the small difference in the values of α_m . Also it is reasonable to regard the difference between the Reynolds number of the NLR test and that of the Ames 185 test as not being too large. Although in both the Ames tests transition remained free, it was fixed in the NLR tests, but it is important to note that the roughness band was as far downstream as $x = 0.3c$. Since it appears from a comparison of the Ames and NLR steady pressures that fixing transition causes no dramatic changes downstream of the band, it seems reasonable to conclude that the band has no significant upstream effect. Thus the results from the Ames 185 test should be comparable with those from the NLR test at least ahead of $x = 0.3c$. In fact, comparison of the steady pressures shows that although there is a disagreement between the Ames and the NLR pressures at the lower surface, the three sets of results for the upper surface are in reasonable agreement in regard to the basic shape, but that there are more irregularities in the Ames distribution, possibly because of surface waviness.

Before comparing the oscillatory measurements, it should be noted that the difference between the Ames and the NLR values of k would not be expected to lead to significant changes in the real component C'/a_0 , although it would have a small effect on the imaginary component, C''/a_0 . The distributions of the oscillatory components are shown in Fig 0.4b and c. With regard to C'/a_0 , in the region ahead of $x = 0.3c$ there are considerable differences both between the two Ames sets and between the Ames and NLR sets. The dip in the region $0.1c < x < 0.2c$ is well established by three points in the Ames test at the higher Re , but is only just in evidence with a single point at the lower Re . This is mentioned in the Introduction to Data Set 5 where it is concluded that this dip is not spurious but must be attributed to a viscous effect. Interestingly the NLR distribution for an even lower Re also shows a single-point dip.

For the distribution of the imaginary component, C''/a_0 the main difference is the vertical displacement between the similarly shaped distributions of NLR and Ames tests. This can be ascribed partly to the known influence of changing k from 0.20 to 0.26. Another contributory factor may be differences between the unsteady effects of wall interference in the two tunnels.

The second example is a comparison of tests that relate closely to CT Case 8 which corresponds to a supercritical design case. The tests chosen for comparison are:

Test	M	α_m (deg)	α_0 (deg)	k	$Re \times 10^{-6}$	Transition
NLR 6708	0.744	0.85	0.6	0.18	2.2	Free
Ames 191	0.752	0.37	0.5	0.20	3.3	Free
Ames 148	0.751	0.37	0.5	0.20	11.4	Free

All the tests were made without fixing transition and the Reynolds numbers for the NLR test and the Ames 191 are sufficiently close for the viscous characteristics of these two tests to be comparable. The third set, Ames 148, is included to show the effects of a large increase in Reynolds number.

There are differences between the NLR and Ames tests in regard to Mach number and mean incidence. As already explained in section 2.1 these differences are deliberate, each (M, α_m) combination having been chosen by the experimenter during preliminary trials to achieve a steady flow that matched the flow calculated by an inviscid theory for the supercritical design case. In a sense, the differences in the parametric settings in the NLR and Ames tunnels can be regarded as compensating to some extent for the differences in steady interference effects and for the differences in the shapes of the models.

The distributions of local Mach number, M_L , for the steady mean incidences, as shown in Fig 0.5a, have the same general shape, are in reasonable agreement on the general level of M_L in the supercritical region and agree on the chordwise position, $x = 0.6c$, at which the deceleration from supercritical flow occurs. However, as for the subsonic example, the Ames distributions have a waviness over the forward half of the chord that is not present in the NLR distribution. Also there are significant differences in the deceleration gradients $dM_L/d(x/c)$ where the abrupt deceleration begins.

Comparisons of the oscillatory pressures are shown in Fig 0.5b and c. Each set of results include peaks in $-C'/a_0$ and $-C''/a_0$ close to the beginning of the deceleration

from supercritical flow, the highest Re producing the highest peaks. Whilst the waviness in the Ames distributions is not unexpected in view of the waviness in the M_1 distributions, there are serious differences between the Ames and NLR results in regard to the mean level of C_p'/α_0 in the region $0.3c < x < 0.6c$.

Also there are serious differences for both C_p'/α_0 and C_p''/α_0 in the region $0.6c < x < 1.0c$ where, surprisingly, it is the Ames results for the higher, and not the lower, Re that agree better with the NLR results. It is remarkable that over the rear of the chord, $0.7c < x < 1.0c$, there are such large differences between the three sets of unsteady pressures when the steady pressures there are in relatively good agreement. Probably the explanation is that the unsteady pressures over the rear part of the chord are dependent on the convection of the vorticity generated by the unsteady processes occurring upstream - in the present case the unsteady behaviour where the supercritical flow is first decelerated. In other words, over the rear of the chord, the effects of changing test conditions on the unsteady pressures are more likely to correlate with the effects of the changes on the steady pressures at more forward, rather than local, positions.

It will now be clear that both of the previous examples include discrepancies that cannot readily be attributed to differences in the models or in the test parameters. Since the ratio of tunnel height to model chord is 6.7 for the Ames tests and 3.1 for the NLR tests it is tempting to ascribe at least some of the discrepancies to differences in tunnel interference and furthermore to give more 'weight' to the data from the tunnel with the larger ratio. However, whilst interference may indeed be the reason, without further evidence and analysis it may be better to regard the differences simply as typical uncertainties inherent in unsteady wind-tunnel measurements.

8 COMPARISON BETWEEN THEORY AND EXPERIMENT

The use of experimental data as qualitative information requires no special comment - it is when the data are to be used for numerical comparisons with theoretical computations that difficulties arise.

The principal aim of computational development is naturally directed towards full-scale aircraft. One of the difficulties in making comparisons with wind-tunnel results arises because the experiments include features, particularly tunnel interference, which have no counterparts in the aircraft situation. The difficulties of applying interference corrections to the measurements have already been discussed. If no assurance can be given that the interference effects on a particular set of data are negligible, either theory must be diverted from its main aim and extended to include a mathematical representation of the tunnel boundaries in the computational model: or, if that is not possible, the probable importance of the effects must be assessed from whatever information on the subject has become available when the comparisons are being made.

A full specification of an unsteady experiment in a tunnel includes:

Model and basic flow

Model shape;
Oscillatory motion: mode, amplitude and frequency;
Stream Mach number, M ;
Mean incidence, α_m (also possibly mean flap angle, δ_m);

Viscous characteristics

Reynolds number;
Transition position;

Tunnel boundary characteristics

Wall geometry;
Ventilation properties.

Comparative computations can vary in type from (a) those that include only the model and basic flow, to (b) those that include the full experimental specification. But at the start of any programme of comparison it is most likely that the chosen type of computation will omit the tunnel boundaries; furthermore the computational model may not fully represent the viscous characteristics of the experiment. In this case, apart from the shape of the model and the oscillatory motion, the main parameters entering the computation will be M and α_m . If tunnel interference (or viscosity) has had a serious effect on the measurements, then it is hardly likely that computations made for the experimental specification (M, α_m)_E will yield results in agreement with the experiment.

In the particular case when a shockwave is present, it is clear that the experimental and theoretical distributions of unsteady pressure will not agree unless there is already an agreement with regard to the mean position and strength of the shock. But more generally for all types of flow, it would seem that an agreement on the steady pressure distribution is a prerequisite to an agreement on the unsteady pressures.

Whilst it may be true that there is generally no free-air equivalent of the tunnel condition, it is possible that an improved comparison of unsteady pressure may result if the calculations are made for a different condition (M, α_m)_C which gives better agreement

for the steady pressure distributions. In effect, the comparison will no longer be based on identities of stream Mach number and mean incidence but instead on similarity of the steady pressure distributions or, more aptly, on similarity of the distributions of local Mach number M_L . If such a method of comparison is adopted, steady computations would need to be made over ranges of M and α_m to seek some agreement in the distributions of M_L before any unsteady calculations are performed. As previously mentioned in section 2.1, such adjustments to the steady mean conditions have already been suggested for the supercritical design case for the NLR 7301 airfoil of Data Sets 4 and 5.

A caution is necessary here. Should a theoretical condition $(M, \alpha_m)_C$ be found that gives an M_L distribution exactly matching that of an experimental condition $(M, \alpha_m)_E$, thus supposedly compensating for the steady interference effects, it does not follow that the compensation extends to the unsteady interference or even to the interference on a quasi-steady change. This should be clear from Fig 0.2. The point needs to be kept in mind when making unsteady comparisons between theory and measurements for the steady-matched supercritical design cases of Data Sets 4 and 5.

When a comparison is made across an appreciable difference in stream Mach number, there is a question of choice concerning the form of the non-dimensional unsteady aerodynamic quantities that are to be compared. This arises because local Mach number M_L is related uniquely to p/p_t but not to C_p : obtaining identity in the values of M_L entails a difference in the values of C_p . Then, since in effect p/p_t rather than C_p is being used for the steady matching, it would seem more appropriate for the comparison of unsteady data to be made for non-dimensional quantities such as \bar{p}/p_{t0} (already mentioned in section 4) rather than the conventional quantities typified by $\bar{C}_p/\phi_0 = \bar{p}/q\phi_0$. To give an example: if the two stream Mach numbers over which the comparison is being made are $M = 0.80$ and $M = 0.85$, then an exact agreement between the values of \bar{p}/p_{t0} would entail a difference of approximately 7% in the corresponding values of \bar{C}_p/ϕ_0 . However, for small differences in M , the matter is usually unimportant, particularly if the differences lie within the range of experimental uncertainty. Note that the unsteady measurements of Data Set 7 are presented as values of \bar{p}/p_{t0} because they were originally used for comparisons between different tunnels.

The preceding discussion has assumed that the tunnel walls are not taken into account in the calculations. If the intention is to include the tunnel boundaries in the computational model it may be difficult to define a mathematical boundary condition sufficiently representative of the ventilated walls of the experiment. It may then be desirable to make separate calculations for each of the two extreme conditions representing closed and open boundaries, as has been done in Ref 0.12 and possibly make a third calculation for some intermediate homogeneous boundary condition.

In summary, the basis on which the experimental and computational unsteady data are compared may take any of the following forms:

- Same class of flow;
- Similarity of M_L distribution;
- Identity of basic flow parameters (M, α_m) . Possibly also identity of viscous parameters, Re and transition position;
- Full experimental specification including the tunnel boundaries.

9 SUGGESTIONS FOR FUTURE EXPERIMENTS

The need for further experimental data will naturally depend on the early comparisons with the present data. If the agreement is good, the only question to arise would be whether all the significant features associated with full-scale aircraft had been catered for. In this connection it will be noted that, although a supercritical section is included in the Compendium, there are no data for a supercritical wing. However, this omission will be overcome when oscillatory pressure measurements become available for the LANN wing whose geometry and CT Cases are defined in Ref 0.2.

In the more likely event of differences being found between the computations and the experiments, there may be a need for new experiments. Before discussing what form these should take, it needs to be noted that the experimental programmes from which the present Data Sets were abstracted predate the choice of the CT Cases. Not all the experiments were specifically designed to provide data for the kind of close numerical comparisons now proposed.

In future it may be desirable to give more attention to overcoming the uncertainties of tunnel interference, say by including in any new tests the effects of changing the characteristics of the tunnel walls. The desirability of fixing transition needs to be re-examined. There could be advantages in making measurements of boundary-layer thickness under steady conditions so that these could be related to viscous calculations. Also it may be necessary to take more account of, or to place greater restraint on, the elastic distortions when 3-D configurations are being tested.

In addition there are two general matters that merit discussion and which to some extent are interrelated. These are (1) the form of the comparisons and (2) the method of communicating the experimental data.

Regarding the first of these matters, it is evident that the importance of variation of the main parameters was fully recognized when the CT Cases were selected. Completion of the computations for all cases for a configuration and their comparison with experiment is intended to demonstrate how well theory can cope with the different situations. But the intervals between consecutive values of the parameters are necessarily rather wide so that the comparisons tend to appear as a series of single-point correspondences. That is, for each case the experimental results for a particular condition $(M, \alpha_m)_E$ will be compared with computed results for the same or a related condition $(M, \alpha_m)_C$. Whilst single-point comparisons may be satisfactory for comparing one computational method with another, they may not be ideal for comparing computation with experiment: one reason being the inevitable uncertainties and sensitivities of the experimental results. It would be preferable to make comparisons of the variations of the aerodynamic quantities with the main parameters such as M and α_m , in the immediate vicinity of the corresponding condition (M, α_m) , thereby taking account of the parametric sensitivities. In practice this could mean a comparison between, on the one hand the data for a pivotal condition, and on the other, data for a mesh of points surrounding the pivot point. Whether in a planned programme, the matrix of data is provided by the computations or the experiments will probably depend to some extent on the relative costs of computation and experiment. On this matter it is noted that although the capital cost of mounting an experiment is large, the running cost of additional measurements may be relatively low.

The possibility of using a greater quantity of experimental data leads to a consideration of the second matter, the means by which the data are communicated. It is obvious that printed tables cannot be used until they have been read and some manual action performed. This procedure is acceptable provided the listings are not too extensive, but the labour involved, quite apart from the amount of paper required, inhibits the use of large amounts of data in this form. Rather than printed tables it is suggested that in future the data be communicated by computer-readable magnetic tape. To give an example of the practicality of this suggestion, all the results of the NORA tests from two large tunnels, some 177 cases in all, can be made available on a standard 200 mm diameter magnetic tape. By using this means of communication, a computer available to the theoretician could present visual displays of the effects of parametric variations and indeed show the comparisons themselves.

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Table 0.1
THE AGARD AEROELASTIC CONFIGURATIONS

Configuration	Motion	Experimental data	
		Source	Present position
<u>2-Dimensional</u> Parabolic arc	Pitch and plunge oscillations	-	No experiments
NACA 64A006	Flap oscillation	NLR	Data Set 1. CT Cases 1,2,3,5,6,7,8*,10*,11
NACA 64A010 NASA Ames model	Pitch oscillation	Ames	Data Set 2. CT Cases 1,2,3,4,5,6*,7,8,9,10*
NACA 0012	Pitch oscillation and transient	ARA	Data Set 3. CT Cases 1*,2,3,5,6,7,8*
MBB-A3	Pitch and plunge oscillations	MBB	Steady data only
DO A1	Pitch oscillation	-	No experiments
NLR 7301	Pitch oscillation	NLR	Data Set 4. CT Cases 1,2,3,4,5,6,8*
		Ames	Data Set 5. CT Cases 1,2,3,4,5,6,7,8*,9
	Flap oscillation	NLR	Data Set 4. CT Cases 10,11,12,14
<u>3-Dimensional</u> Rectangular wing	Pitch oscillation about 2 axes	RAE	Experiments planned for 1984
RAE wing A	Pitch oscillation	RAE	Possibility of future experiments
	Flap oscillation	RAE	Data Set 6. CT Cases 4,5,8,9*,11
NORA model	Oscillation about swept axis	GARTEur [†]	Data Set 7. CT Cases 1,2*,3,4,5*,6*,7,8,9
ZKP wing	Flap oscillation	VFW	Data available in 1983
LANN wing	Pitch oscillation	NLR	Data probably available in 1983

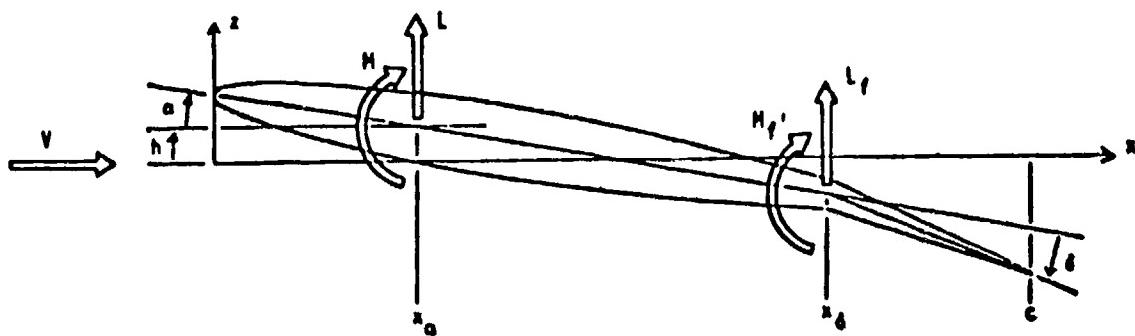
* Denotes the priority cases for computational tests.

† The NORA experiments were made under the auspices of the Group for Aeronautical Research and Technology in Europe.

Table 0.2
NLR 7301 AEROFOIL PITCHING ABOUT 0.4c

Flow	Case	Run No. or DI	M	a_m	a_0	k	$Re \times 10^{-6}$	Transition
Subsonic	<u>CT Case 1</u>	-	0.500	0.40	0.5	0.098	-	-
	Data Set 4	1601	0.499	0.85	0.55	0.098	1.70	Fixed
	Data Set 5 {	184	0.508	0.58	0.50	0.050	2.53	Free
		168	0.505	0.58	0.51	0.049	9.33	Free
	<u>CT Case 2</u>	-	0.500	0.40	0.5	0.263	-	-
	Data Set 4	1301	0.498	0.85	0.44	0.262	1.70	Fixed
Transonic with shock	Data Set 5 {	185	0.508	0.58	0.50	0.197	2.53	Free
		170	0.505	0.58	0.50	0.198	9.33	Free
	<u>CT Case 3</u>	-	0.700	2.00	0.5	0.072	-	-
	Data Set 4	3805	0.696	3.00	0.42	0.072	2.11	Fixed
	Data Set 5 {	204	0.710	2.53	0.50	0.050	3.14	Free
		197	0.700	2.53	0.49	0.050	12.0	Free
Super- critical design	<u>CT Case 4</u>	-	0.700	2.00	1.0	0.072	-	-
	Data Set 4	3905	0.696	3.00	0.98	0.072	2.11	Fixed
	Data Set 5 {	206	0.710	2.53	1.01	0.050	3.14	Free
		199	0.700	2.53	1.01	0.050	12.0	Free
	<u>CT Case 5</u>	-	0.700	2.00	0.5	0.192	-	-
	Data Set 4	52705	0.695	3.00	0.55	0.192	2.12	Fixed
	Data Set 5 {	205	0.710	2.53	0.58	0.199	3.14	Free
		198	0.700	2.53	0.49	0.201	12.0	Free
	<u>CT Case 6</u>	-	0.721	-0.19	0.5	0.068	-	-
	Data Set 4	9608	0.744	0.85	0.46	0.068	2.23	Free
	Data Set 5 {	190	0.752	0.37	0.50	0.050	3.30	Free
		132	0.752	0.37	0.50	0.050	6.20	Free
	<u>CT Case 7</u>	-	0.721	-0.19	1.0	0.068	-	-
	Data Set 4	-	-	-	No measurements	-	-	-
	Data Set 5 {	136	0.752	0.37	1.01	0.050	6.20	Free
		150	0.751	0.37	1.00	0.050	11.4	Free
	<u>CT Case 8*</u>	-	0.721	-0.19	0.5	0.181	-	-
	Data Set 4	6708	0.744	0.85	0.61	0.181	2.22	Free
	Data Set 5 {	191	0.752	0.37	0.50	0.200	3.30	Free
		134	0.752	0.37	0.49	0.200	6.20	Free
		148	0.751	0.37	0.50	0.201	11.4	Free
	<u>CT Case 9</u>	-	0.721	-0.19	0.5	0.453	-	-
	Data Set 4	-	-	-	No measurements	-	-	-
	Data Set 5 {	135	0.752	0.37	0.50	0.300	6.20	Free
		149	0.751	0.37	0.50	0.301	11.4	Free

* Denotes a priority case for computations



$$q = 1/2 \rho V^2$$

$$C_p = \frac{D - D_\infty}{q}$$

$$\Delta C_p = C_{p,\text{lower}} - C_{p,\text{upper}}$$

$$L = q c c_L$$

$$L_f = q c c_{L,f}$$

$$M = q c^2 c_M$$

$$M_f = q c^2 c_{M,f}$$

$$c_L = \frac{2}{\pi} \int_0^c c c_L dy$$

$$c_M = \frac{2}{3c_r} \int_0^c c^2 c_M dy$$

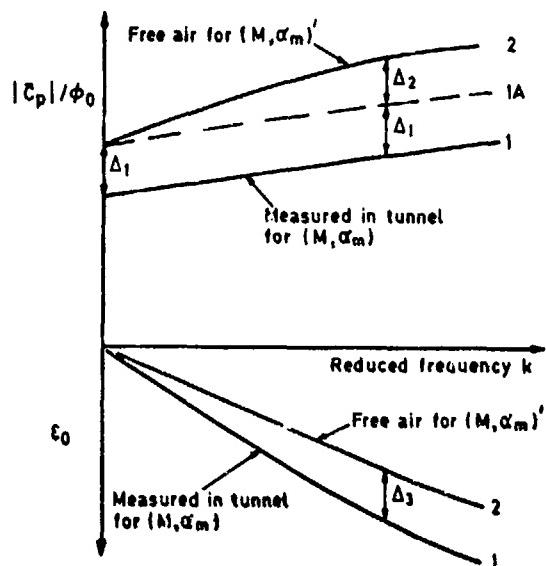
$$c_H = \frac{2}{3c_r} \int_{\text{control span}} c^2 c_H dy$$

$$c_L = \phi_{\text{airfoil}} C_p d c + \int_0^c \Delta C_p dc$$

$$c_M = \phi_{\text{airfoil}} C_p (z_a/c - c - z/c + dz/dc) dc + \int_{z_a/c}^c \Delta C_p (z_a/c - c) dc$$

$$c_H = \phi_{\text{flap}} C_p (z_f/c - c - z/c + dz/dc) dc + \int_{z_f/c}^c \Delta C_p (z_f/c - c) dc$$

Fig 0.1 Wing section and total force and moment definitions from Ref 0.2



It is assumed that a steady condition (M, α_m) in the tunnel is equivalent to a steady condition $(M, \alpha_m)'$ in free air.

Displacement Δ_1 is an effect of steady interference; Δ_2 and Δ_3 are the effects of unsteady interference

Fig 0.2 Schematic diagram illustrating tunnel interference on the modulus and phase of oscillatory pressure

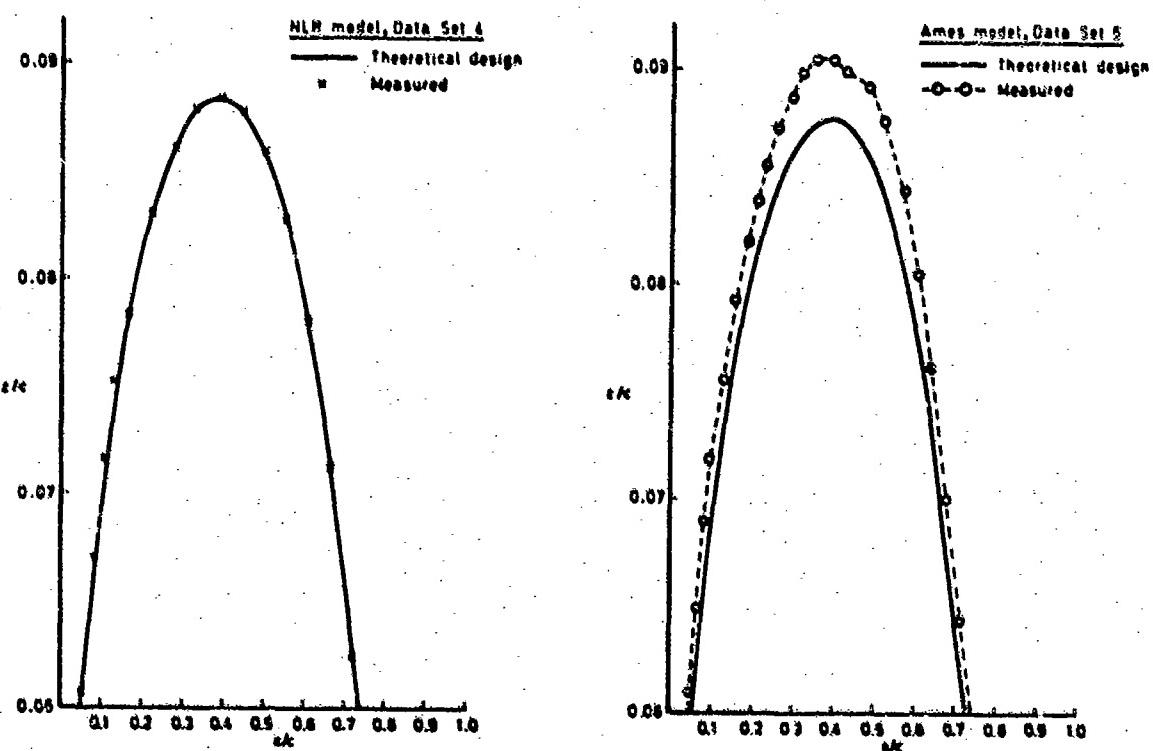


Fig 0.3 NLR 7301 Airfoil. Comparison between physical models and design shape. Profile height z/c for part of upper surface. (Note: the base line used to define z is not the same for both models; this is irrelevant to the comparisons)

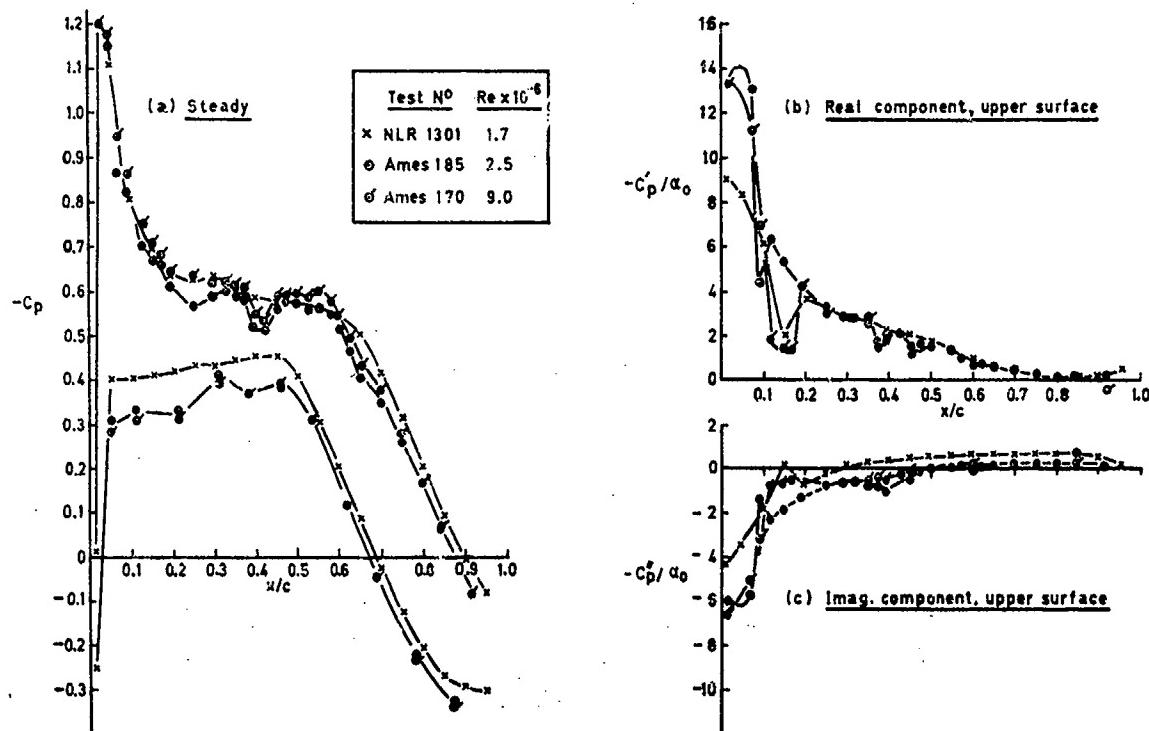


Fig 0.4 NLR 7301 Airfoil. Comparison of NLR and Ames data relating to CT Case 2
(subsonic $M = 0.5$)

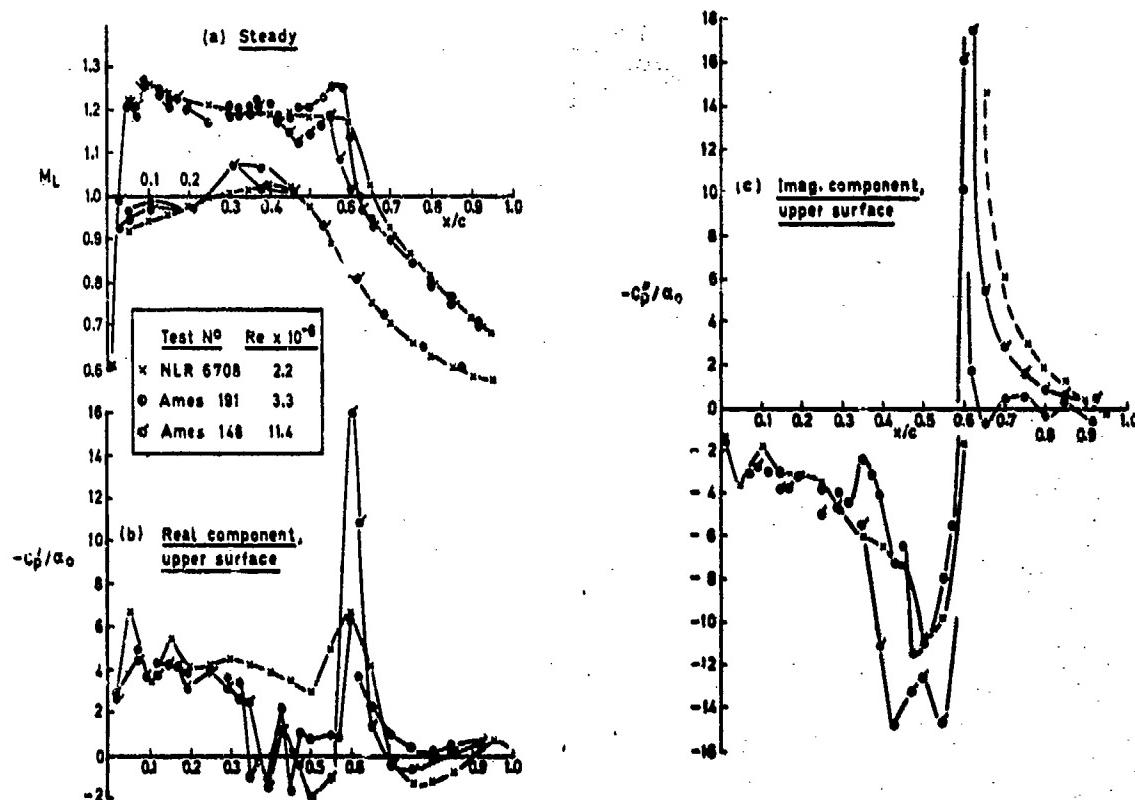


Fig 0.5 NLR 7301 Airfoil. Comparison of NLR and Ames data relating to CT Case 8
(Supercritical design case)

DATA SET 1

NACA 64A006 OSCILLATING FLAP

by

R.J. Zwaan, NLR

INTRODUCTION

The wind tunnel model which had a NACA 64A006 airfoil section, was fitted with a trailing-edge flap of 25 per cent of the chord. The maximum thickness of this symmetrical airfoil is 6 per cent and is located at about 28 per cent of the chord. During the test the main surface was clamped at the wind tunnel side walls, whereas the flap could be driven in a harmonic motion about an axis at 75 per cent of the chord. The flap had no aerodynamic balance.

In the set of two-dimensional aeroelastic configurations this airfoil represents the category of small thickness and conventional airfoils (roof-top type). The characteristics are illustrated in figure 1.1, presenting the development of the steady and unsteady pressure distributions with Mach number for a given frequency. Passing the critical Mach number, $M^* \approx 0.85$, the measured unsteady pressure distributions start to deviate from the calculated distributions under the influence of shocks at both sides. The calculated results are based on lifting surface theory.

Lift and moment coefficients are given in figure 1.2 for a frequency of 120 Hz. An at least qualitative agreement exists between experiment and theory up to $M=0.85$. Results are also given for $k = 0$, see figure 1.3. The differences between experiment and theory are appreciably larger now, which can be ascribed partly to tunnel wall interference.

1 AIRFOIL

1.1 Designation	NACA 64A006
1.2 Type of airfoil	Roof top, 6 % thick, symmetrical
1.3 Geometry	See Table 1.1
1.4 Design condition	Not applicable
1.5 Additional remarks	-
1.6 References on airfoil	Ref. 1.1

2 MODEL GEOMETRY

2.1 Chord length	0.18 m
2.2 Span	0.42 m
2.3 Actual model coordinates and accuracy of measurements	See Table 1.2
2.4 Flap: hinge and gap details	Hinge axis at 0.75 c; gap width 0.1 mm
2.5 Additional remarks	-
2.6 References on model	-

3 WIND TUNNEL

3.1 Designation	NLR Pilot Tunnel
3.2 Type of tunnel	Continuous, closed circuit
3.3 Test section dimensions	Rectangular; see Fig. 1.4 height 0.55 m, width 0.42 m
3.4 Type of roof and floor	10 % slotted top and bottom walls, separate top and bottom plenums
3.5 Type of side walls	Solid side walls
3.6 Ventilation geometry	See Fig. 1.4
3.7 Thickness of side wall boundary layer	Thickness 10 % of test section semi-width, no special treatment
3.8 Thickness of boundary layers at roof and floor	Not measured; probably comparable with side wall boundary layers
3.9 Method of measuring Mach number	Derived from static pressure measured upstream of model and from total pressure measured in settling chamber
3.10 Uniformity of Mach number over test section	See Fig. 1.5
3.11 Sources and levels of noise or turbulence in empty tunnel	Turbulence/noise level, see Fig. 1.6
3.12 Tunnel resonances	No evidence

- 3.13 Additional remarks For two-dimensionality of the flow see Ref. 1.3
 3.14 References on tunnel Ref. 1.2

4 MODEL MOTION

- 4.1 Mode of applied motion Flap oscillation
 4.2 Range of amplitude $\delta_0 \approx 1^\circ$
 4.3 Range of frequency $f = 0$ to 120 Hz; $k = 0$ to 0.4
 4.4 Method of application Electrodynamic excitation at both sides of the flap, using adjustable spring stiffness
 4.5 Purity of applied motion Checked by spectral analysis; no data stored
 4.6 Natural frequencies and normal modes of model No interference with natural vibration modes
 4.7 Static or dynamic elastic distortion during tests Negligible
 4.8 Additional remarks

5 TEST CONDITIONS

- 5.1 Tunnel height/model chord ratio 3.1
 5.2 Tunnel width/model chord ratio 2.3
 5.3 Range of Mach number $M = 0.5$ to 1.0
 5.4 Range of tunnel total pressure Atmospheric
 5.5 Range of tunnel total temperature 313 ± 1 K
 5.6 Range of model steady, or mean, incidence $a_m: -4^\circ$ to 0° ; $\delta_m: -3^\circ$ to 3°
 5.7 Definition of model incidence Zero incidence defined by matching upper and lower static pressure distribution (applicable because of airfoil symmetry)
 5.8 Position of transition, if free Not applicable
 5.9 Position and type of trip, if transition fixed 2.5 mm strip of carborundum grains at 0.1 c
 5.10 For mixed flow, position of sonic boundary in relation to roof and floor Not measured
 5.11 Flow instabilities during tests No evidence
 5.12 Additional remarks -
 5.13 References describing tests Ref. 1.4

6 MEASUREMENTS AND OBSERVATIONS

- 6.1 Steady pressures for the mean conditions
 6.2 Steady pressures for small changes from the mean conditions
 6.3 Quasi-steady pressures
 6.4 Unsteady pressures
 6.5 Steady forces for the mean conditions
 6.6 Steady forces for small changes from the mean conditions
 6.7 Quasi-steady forces
 6.8 Unsteady forces
 6.9 Measurement of actual motion at points on model
 6.10 Observation or measurement of boundary layer properties
 6.11 Visualization of surface flow
 6.12 Visualization of shockwave movements
 6.13 Additional remarks

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7	INSTRUMENTATION	
7.1	Steady pressures	
7.1.1	Position of orifices spanwise and chordwise	See 7.2.1
7.1.2	Type of measuring system	See 7.2.3
7.2	Unsteady pressures	
7.2.1	Position of orifices spanwise and chordwise	See Figs 1.7 and 1.8
7.2.2	Diameter of orifices	0.8 mm
7.2.3	Type of measuring system	38 pressure tubes + 6 in situ pressure transducers
7.2.4	Type of transducers	±2.5 psi and ±5 psi Statham differential pressure transducers, and ±5 psi Kulite miniature pressure transducers
7.2.5	Principle and accuracy of calibration	Calibration uses transfer functions of pressure tubes, see Ref. 1.4; for accuracy see 9.10
7.3	Model motion	
7.3.1	Method of measurement	See Fig. 1.7
7.3.2	Accuracy	See 9.10
7.4	Processing of unsteady measurements	
7.4.1	Method of acquiring and processing measurements	See Fig. 1.9
7.4.2	Type of analysis	Signal analysis of TFA over 20 cycles for $f = 30$ Hz and 60 cycles for $f = 120$ Hz
7.4.3	Unsteady pressure quantities obtained and accuracies achieved	Fundamental harmonics; for accuracy see 9.10
7.4.4	Method of integration to obtain forces	Trapezoidal rule
7.5	Additional remarks	-
7.6	References on techniques	Refs 1.4, 1.5
8	DATA PRESENTATION	
8.1	Test cases for which data could be made available	Table 1.3
8.2	Test cases for which data are included in this document	Table 1.4
8.3	Steady pressures	Mean pressures in Tables 1.5 to 1.18
8.4	Quasi-steady or steady perturbation pressures	Steady pressure derivatives in Tables 1.5, 1.8, 1.11, 1.14 and 1.17
8.5	Unsteady pressures	Tables 1.6, 1.7, 1.9, 1.10, 1.12, 1.13, 1.15, 1.16 and 1.18
8.6	Steady forces or moments	-
8.7	Quasi-steady or steady perturbation forces	See 8.4
8.8	Unsteady forces and moments	See 8.5
8.9	Other forms in which data could be made available if required	-
8.10	References giving other presentations of data	Ref. 1.6
9	COMMENTS ON DATA	
9.1	Accuracy	
9.1.1	Mach number	±0.002
9.1.2	Steady incidence	±0.02°
9.1.3	Reduced frequency	±0.0005
9.1.4	Steady pressure coefficients	Not known
9.1.5	Steady pressure derivatives	Not known
9.1.6	Unsteady pressure coefficients	Not known
9.2	Sensitivity to small changes of parameter	No evidence
9.3	Spanwise variations	No evidence
9.4	Non-linearities	Part of analysis of experimental results; see Ref. 1.4

9.5	Influence of tunnel total pressure	-
9.6	Wall interference corrections	No corrections included
9.7	Other relevant tests on <u>same model</u>	None
9.8	Relevant tests on other model of nominally the <u>same</u> airfoil	Unknown
9.9	Any remarks relevant to comparison between experiment and theory	Comparisons of experiment and theory including various calculation methods are given in Ref. 4
9.10	Additional remarks	No systematic investigations of separate accuracies have been performed; accuracy of lift and moment coefficients is estimated to be 5 to 10 per cent in magnitude and 3 to 6 degrees in phase angle
9.11	References on discussion of data	Refs 1.4, 1.7

10 PERSONAL CONTACT FOR FURTHER INFORMATION

R.J. Zwaan, National Aerospace Laboratory (NLR), Anthony Fokkerweg 2, 1059 CM Amsterdam,
The Netherlands

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| 1.5 | P.H. Fuykschot
L.J.M. Joosten | DYDRA - Data logger for dynamic measurements
NLR MP 69012 U, 1969 |
| 1.6 | H. Tijdemann
P. Schippers | Results of pressure measurements on an airfoil with oscillating flap in two-dimensional high subsonic and transonic flow (zero incidence and zero mean flap position)
NLR TR 73078 U, 1973 |
| 1.7 | R. Houwink | Some remarks on boundary layer effects on unsteady airloads
AGARD-CP-296, 1981 |
| 1.8 | S.R. Bland | AGARD Two-dimensional aeroelastic configurations
AGARD-AR-156, 1979 |

12 NOTATION AND LIST OF SYMBOLS

DATA SET	STANDARD
ALPHA	mean wing incidence, α_m , deg
C	flap amplitude, δ_o , deg; see Note 2 below
CP	steady mean pressure coefficient, C_p
DCP	oscillatory pressure coefficient ($k \neq 0$), tabulated as REal, IMaginary, MODulus and ARGument, equivalent to $-C_p/\delta_o$, in which $\bar{C}_p/\delta_o = (C_p/\delta_o) + i(C_p''/\delta_o)$. RE, IM, MOD in rad ⁻¹ , ARG in deg. If $k = 0$, then DCP = $-(C_p(+\delta_o) - C_p(-\delta_o))/2\delta_o$
DELTA	mean flap angle, δ_m , deg
F	frequency, f, Hz
K	reduced frequency, k = $\omega c/V$
KC, k_c	oscillatory wing lift coefficient, \bar{C}_L/δ_o , rad ⁻¹
M	mean local Mach number, M_L
MC, m_c	oscillatory wing pitching moment coefficient (about 0.25 c), $-2 \bar{C}_M/\delta_o$, rad ⁻¹
NC, n_c	oscillatory flap hinge moment coefficient, $-2 \bar{C}_N/\delta_o$, rad ⁻¹
PO	total pressure, p_t , Pa
Q	dynamic pressure, q, Pa
RC	oscillatory flap lift coefficient, \bar{C}_{L_f}/δ_o , rad ⁻¹
RE	Reynolds number based on wing chord, Re
+	(suffix) upper side
-	(suffix) lower side

* (superscript) critical value

Note 1: Symbols not mentioned here conform to the notation in the General Review

Note 2: The oscillatory motion is defined as $\delta = \delta_0 \sin \omega t$, in accordance with the General Review. The equation for a corresponding oscillatory pressure reads:

$$p(t) = p_m + p' \sin \omega t + p'' \cos \omega t + \text{etc.}$$

Similar expressions hold for the aerodynamic coefficients.

TABLE 1.1

Contour data of the NACA 64A006 airfoil

x (% c)	z (% c)	x (% c)	z (% c)
0	0	40	2.999
0.5	0.485	45	2.945
0.75	0.585	50	2.825
1.25	0.739	55	2.653
2.5	1.016	60	2.438
5.0	1.399	65	2.188
7.5	1.684	70	1.907
10	1.919	75	1.602
15	2.283	80	1.285
20	2.557	85	0.967
25	2.757	90	0.649
30	2.896	95	0.331
35	2.977	100	0.013

L.E. radius: 0.246 % c

TABLE 1.2

Actual contour data of the NACA 64A006 airfoil
(measures per cent of chord)

x	z _{upper}	z _{lower}
1.25	0.742	-0.742
2.50	1.025	-1.025
5.00	1.405	-1.405
7.50	1.686	-1.686
10.00	1.919	-1.922
15.00	2.283	-2.283
20.00	2.558	-2.555
25.00	2.758	-2.758
30.00	2.894	-2.889
35.00	2.975	-2.969
40.00	2.991	-2.989
45.00	2.942	-2.936
50.00	2.822	-2.819
55.00	2.655	-2.642
60.00	2.430	-2.425
65.00	2.194	-2.169
70.00	1.908	-1.894
75.00	-	-
80.00	1.310	-1.310
85.00	0.989	-0.989
90.00	0.668	-0.668
95.00	0.346	-0.346
100.00	0.027	-0.027

TABLE 1.3

Test program for the NACA 64A006 airfoil with flap

Test condition	FREQ. (Hz)	MACH NUMBER											
		.50	.75	.775	.80	.825	.85	.875	.90	.92	.94	.96	.98
$\alpha_m = 0^\circ$ $\delta_m = 0^\circ$	0	x	x		x	x	1	x	x	x	x	x	x
	10	x			x	x	x	x	x	x	x	x	
	20	x					x						
	30	x			x	x	x	x	x	x	x	x	
	90	x			x	x	x	x	x	x	x	x	
	120	x	x	x	x	x	x	x	x	x	x	x	x
$\alpha_m = 0^\circ$ $\delta_m = 3^\circ$	0	x	x		x	x	x	x	x	x	x	x	x
	30	x			x	x	x	x	x	x	x	x	
	120	x	x	x	x	x	x	x	x	x	x	x	
$\alpha_m = -2^\circ$ $\delta_m = 0^\circ$	0	x	x		x	x	x	x	x	x	x	x	x
	30	x			x	x	x	x	x	x	x	x	
	120	x	x	x	x	x	x	x	x	x	x	x	
$\alpha_m = -2^\circ$ $\delta_m = 3^\circ$	0	x	x		x	x	x	x	x	x	x	x	x
	30	x			x	x	x	x	x	x	x	x	
	120	x	x	x	x	x	x	x	x	x	x	x	
$\alpha_m = -2^\circ$ $\delta_m = -3^\circ$	0	x	x	x	x	x	x	x	x	x	x	x	x
	30	x			x	x	x	x	x	x	x	x	
	120	x	x	x	x	x	x	x	x	x	x	x	
$\alpha_m = -4^\circ$ $\delta_m = 0^\circ$	0	x	x	x	x	x	x	x	x	x	x	x	x
	10	x					x						
	30	x			x	x	x	x	x	x	x	x	
	120	x	x	x	x	x	x	x	x	x	x	x	

AMPLITUDE OF OSCILLATION: $\delta_0 = 1$ DEG

TABLE 1.4
Test cases for the NACA 64A006 airfoil with flap included in Data Set 1

Flow	CT Case				Data Set 1						
	No	M	δ_0	k	Run No	M	δ_0	δ_m	k	$Re \cdot 10^{-6}$	Table
Subsonic	z1	0.800	1.5	0	-	0.800	1.5	0	0	2.34	1.5
	1	0.800	1.0	0.064	40904	0.794	1.09	0.15	0.064	2.32	1.6
	2	0.800	1.0	0.253	40807	0.804	1.11	0.00	0.253	2.35	1.7
	z2	0.825	1.5	0	-	0.825	1.5	0	0	2.36	1.8
	3	0.825	1.0	0.062	40905	0.824	1.09	0.15	0.062	2.36	1.9
	4	0.825	2.0	0.062	No measurement						
	5	0.825	1.0	0.248	40305	0.822	0.95	0.20	0.248	2.28	1.10
Transonic	z3	0.850	1.5	0	-	0.850	1.5	0	0	2.39	1.11
	6	0.850	1.0	0.060	40906	0.853	1.10	0.16	0.060	2.40	1.12
	7	0.850	1.0	0.240	40806	0.854	1.05	0.02	0.240	2.41	1.13
	z4	0.875	1.5	0	-	0.875	1.5	0	0	2.43	1.14
	8*	0.875	1.0	0.059	40907	0.877	1.13	0.15	0.059	2.43	1.15
	9*	0.875	2.0	0.059	No measurement						
	10*	0.875	1.0	0.234	40807	0.879	1.08	0.01	0.234	2.44	1.16
	z5	0.960	1.5	0	-	0.960	1.5	0	0	2.51	1.17
	11	0.960	1.0	0.054	40911	0.966	1.03	0.00	0.054	2.53	1.18
	12	0.960	1.0	0.214	No measurement				0.18		

Remarks on Table 1.4

Cases z1 to z5 are extra to the computational cases identified in reference 1.8. They correspond to zero-frequency ($k = 0$) experimental data that are closely related to the CT Cases for which $k \neq 0$. The asterisks denote Priority Cases.

In all cases $a_m = 0$. Transition is fixed at 0.15 c.

TABLE 1.5

$M = .800$ $F = 0$ $\text{ALPHA} = 0.00$ $KC = 1.32$
 $\text{DELTA} = 0.00$ $MC = .612$
 $C = 1.5$ $NC = .0372$

UPPERSIDE				LOWERSIDE				
X/C	CP +	M +	DCP +	CP -	M -	DCP -	RE	IM
.010	-.005	.802	3.552	.029	.787	-.3.609	0.0	
.050	-.154	.870	2.292	-.143	.865	-.2.253	0.0	
.100	-.192	.887	1.833	-.179	.881	-.1.833	0.0	
.200	-.236	.907	1.680	-.238	.908	-.1.719	0.0	
.300	-.268	.922	1.719	-.273	.924	-.1.692	0.0	
.400	-.290	.932	1.890	-.293	.933	-.2.005	0.0	
.450	-.276	.926	1.967	-.257	.921	-.1.986	0.0	
.500	-.249	.913	1.890	-.250	.914	-.2.024	0.0	
.550	-.216	.898	1.944	-.213	.897	-.1.986	0.0	
.600	-.179	.881	2.005	-.176	.880	-.2.158	0.0	
.650	-.150	.868	2.215	-.144	.868	-.2.349	0.0	
.700	-.114	.854	2.597	-.103	.847	-.2.616	0.0	
.725	-.104	.847	2.941	-.084	.838	-.2.826	0.0	
.750	-.096	.843	4.431	-.097	.797	-.7.086	0.0	
.775	-.071	.832	3.458	-.053	.824	-.3.724	0.0	
.800	-.046	.821	2.807	-.034	.815	-.2.769	0.0	
.850	-.010	.805	1.661	-.004	.802	-.1.699	0.0	
.900	.023	.790	.974	-.010	.786	-.974	0.0	
.950	.067	.770	.458	.072	.768	-.477	0.0	

TABLE 1.6

RUNNO 40904

M = .794 F = 30.0 ALPHA = 0
 P0 = 10429 DELTA M = .15
 RE = 2.32E6 K = .064 C = 1.00
 Q = 3037.30

KC =	RE	IM	RE	IM	X5 =	X6 =	
1.016	-0.260	RC =	.2768	.0112	1.334E-3	1.366E-3	1
NC =	.640	INC =	.0385	.0028			0

X/C	CP+	M+	UPPERSIDE				LOWERSIDE					
			RE	IM	DCP+	MOD ARG	RE	IM	DCP+	MOD ARG		
.010	-0.035	.811	.671	-1.474	1.619	-65	.077	.759	-0.736	1.554	1.719	115
.050	-0.175	.873	.342	-0.753	.827	-66	-0.120	.847	-0.678	1.050	1.250	123
.100	-0.226	.897	.657	-0.853	1.077	-52	-0.166	.867	-0.737	.895	1.159	129
.200	-0.252	.909	.991	-0.787	1.266	-38	-0.222	.893	-1.115	.826	1.387	143
.300	-0.279	.921	1.245	-0.683	1.420	-29	-0.256	.908	-1.276	.708	1.459	151
.400	-0.304	.932	1.628	-0.554	1.719	-19	-0.279	.919	-1.578	.605	1.690	159
.450	-0.287	.925	1.744	-0.403	1.790	-13	-0.260	.910	-1.665	.490	1.736	164
.500	-0.263	.914	1.826	-0.301	1.850	-9	-0.235	.898	-1.825	.379	1.864	168
.550	-0.222	.895	1.915	-0.198	1.925	-6	-0.199	.882	-1.927	.288	1.948	172
.600	-0.190	.881	2.034	-0.113	2.038	-3	-0.165	.867	-2.105	.185	2.113	175
.650	-0.159	.866	2.155	-0.136	2.159	-4	-0.127	.850	-2.302	.118	2.305	177
.700	-0.125	.851	2.258	-0.253	2.272	-6	-0.089	.833	-2.649	.043	2.650	179
.725	-0.108	.844	2.658	-0.213	2.667	-5	-0.071	.825	-2.885	.023	2.885	180
.750	-0.068	.825	4.948	.409	4.965	5	.013	.787	-5.276	1.571	5.505	163
.775	-0.085	.833	4.097	.224	4.103	3	-0.030	.806	-3.821	-0.047	3.822	181
.800	-0.058	.821	3.038	.335	3.057	6	-0.018	.801	-2.943	-0.141	2.946	183
.850	-0.018	.803	1.751	.212	1.764	7	.006	.790	-1.738	-0.042	1.739	181
.900	.021	.786	.959	.100	.964	6	.038	.776	-1.066	-0.090	1.069	185
.950	.069	.764	.374	.013	.374	2	.080	.737	-0.581	-0.043	.583	185

TABLE 1.7

RUNNO 40807

M = .804 F = 120.0 ALPHA = 0
 P0 = 10484 DELTA M = 0.00
 RE = 2.35E6 K = .253 C = 1.11
 Q = 3097.63

KC =	RE	IM	RE	IM	
.830	-0.394	RC =	.3090	.0480	
NC =	.756	INC =	.0419	.0115	

X/C	CP+	M+	UPPERSIDE				LOWERSIDE					
			RE	IM	DCP+	MOD ARG	RE	IM	DCP+	MOD ARG		
.010	-0.031	.815	-1.001	-0.899	1.346	-138	.066	.774	1.043	.914	1.387	41
.050	-0.173	.882	-0.494	-0.510	.710	-134	-0.124	.860	.601	.704	.926	49
.100	-0.225	.906	-0.416	-0.768	.873	-118	-0.171	.882	.476	.847	.971	61
.200	-0.252	.919	-0.081	-1.121	1.124	-94	-0.225	.906	.061	1.128	1.127	67
.300	-0.280	.932	.428	-1.351	1.417	-72	-0.257	.921	-0.448	1.276	1.352	109
.400	-0.306	.944	1.240	-1.468	1.921	-50	-0.282	.933	-1.100	1.307	1.708	130
.450	-0.289	.936	1.647	-1.277	2.084	-38	-0.267	.926	-1.335	1.199	1.795	138
.500	-0.261	.923	1.943	-1.118	2.242	-30	-0.238	.912	-1.668	1.044	1.968	148
.550	-0.223	.905	2.146	-0.900	2.327	-23	-0.203	.896	-1.906	.924	2.118	154
.600	-0.188	.889	2.336	-0.629	2.620	-15	-0.168	.880	-2.217	.664	2.315	163
.650	-0.158	.875	2.582	-0.428	2.617	-9	-0.132	.864	-2.556	.523	2.609	168
.700	-0.126	.861	2.729	-0.180	2.735	-4	-0.095	.847	-2.978	.290	2.992	174
.725	-0.108	.852	3.259	-0.139	3.262	-2	-0.076	.838	-3.286	.212	3.293	176
.750	-0.045	.824	7.188	.060	7.188	0	.008	.890	-6.507	.214	6.510	178
.775	-0.083	.841	4.427	.134	4.429	2	-0.038	.821	-3.953	-0.189	3.957	183
.800	-0.055	.828	3.339	.446	3.368	8	-0.026	.816	-3.090	-0.374	3.121	187
.850	-0.017	.811	1.986	.488	2.045	14	-0.001	.804	-1.833	-0.437	1.885	193
.900	.020	.794	1.105	.407	1.178	20	.032	.789	-1.121	-0.444	1.206	202
.950	.066	.773	.431	.228	.487	28	.074	.770	-0.496	-0.273	.566	209

TABLE 1.8

$M = .825$ $F = 0$ $\text{ALPHA} = 0.00$ $KC = 1.35$
 $P0 = 10426$ $\text{DELTA} = 0.00$ $MC = .640$
 $RE = 2.36E6$ $C = 1.5$ $NC = .0380$

X/C	CP +	M +	UPPERSIDE		LOWERSIDE		DCP -
			RE	IM	CP -	M -	
.010	.017	.817	3.132	0.0	.039	.807	-3.208
.050	-.146	.894	2.081	0.0	-.141	.891	-2.139
.100	-.188	.914	1.680	0.0	-.181	.910	-1.757
.200	-.246	.942	1.623	0.0	-.247	.942	-1.719
.300	-.283	.959	1.852	0.0	-.289	.962	-1.910
.400	-.321	.978	2.349	0.0	-.326	.980	-2.349
.450	-.300	.968	2.311	0.0	-.294	.965	-2.292
.500	-.265	.951	2.081	0.0	-.263	.950	-2.177
.550	-.225	.931	2.062	0.0	-.224	.931	-2.158
.600	-.187	.913	2.177	0.0	-.184	.912	-2.253
.650	-.151	.896	2.406	0.0	-.147	.894	-2.463
.700	-.119	.881	2.750	0.0	-.104	.874	-2.712
.725	-.103	.873	3.132	0.0	-.084	.864	-2.922
.750	-.092	.868	4.660	0.0	-.007	.822	-7.219
.775	-.068	.857	3.991	0.0	-.051	.849	-3.839
.800	-.042	.845	2.845	0.0	-.032	.840	-2.884
.850	-.006	.828	1.661	0.0	.002	.824	-1.699
.900	.029	.811	.935	0.0	.036	.808	-.974
.950	.073	.791	.439	0.0	.079	.788	-.401

TABLE 1.9

RUNNO 40905

$M = .824$ $F = 30.0$ $\text{ALPHAS} = 0$
 $P0 = 10426$ $\text{DELTA} = .15$
 $RE = 2.36E6$ $K = .062$ $C = 1.09$
 $Q = 3175.36$

	RE	IM		RE	IM
KC	1.068	-0.260	RC	.2863	.0195
MC	.681	.022	NC	.0395	.0041

X/C	CP+	M+	UPPERSIDE				LOWERSIDE				DCP-
			RE	IM	MOD	ARG	RE	IM	MOD	ARG	
.010	-.011	.831	.817	-1.351	1.446	-.69	.088	.782	-0.829	1.384	1.401
.050	-.169	.905	.273	-0.707	.758	-.69	-.0116	.878	-0.562	.999	1.147
.100	-.223	.931	.559	-0.839	1.008	-.56	-.0168	.902	-0.608	.915	1.151
.200	-.258	.948	.908	-0.844	1.240	-.43	-.0235	.934	-1.067	.901	1.396
.300	-.294	.966	1.308	-0.793	1.538	-.31	-.0275	.953	-1.354	.817	1.582
.400	-.329	.983	1.956	-0.715	2.082	-.20	-.0308	.969	-1.877	.754	2.023
.450	-.312	.975	2.107	-0.467	2.188	-.12	-.0284	.958	-1.940	.578	2.026
.500	-.278	.958	2.113	-0.271	2.130	-.7	-.0254	.943	-2.030	.391	2.067
.550	-.233	.936	2.065	-0.143	2.069	-.4	-.0212	.923	-2.102	.262	2.119
.600	-.194	.918	2.147	-0.048	2.148	-.1	-.0171	.903	-2.246	.141	2.250
.650	-.162	.902	2.271	-0.053	2.272	-.1	-.0134	.886	-2.447	.080	2.447
.700	-.129	.887	2.346	-0.182	2.353	-.4	-.0092	.866	-2.771	-0.042	2.771
.725	-.112	.878	2.780	-0.133	2.783	-.3	-.0072	.857	-2.994	-0.064	2.995
.750	-.068	.858	5.091	.547	5.120	6	.017	.815	-5.417	1.590	5.645
.775	-.006	.866	4.289	.363	4.304	5	-.0.029	.836	-4.000	-0.133	4.003
.800	-.058	.853	3.173	.468	3.207	6	-.0.016	.831	-3.079	-0.202	3.085
.850	-.014	.832	1.805	.288	1.828	9	.008	.819	-1.793	-0.092	1.795
.900	.024	.815	.967	.135	.977	8	.043	.803	-1.089	-0.128	1.096
.950	.073	.791	.301	.032	.302	5	.084	.784	-0.492	-0.061	.496

TABLE 1.10

RUNNO 40305

M = .822 F = 120.0 ALPHAS = 0
 P0 = 10069 DELTAs = .20
 RE = 2.28E6 Ks = .248 Cs = .95
 Q = 3056.41

KC	RE	IM	RE	IM
.865	-0.480	RCM	.3462	.0481
MC	.861	-0.064	NC	.0477
				.0120

X/C	CP+	UPPERSIDE						LOWERSIDE					
		M+	DCP+		DCP+	CP+	M+	DCP+	DCP+	CP+	M+	DCP+	CP+
			RE	IM				RE	IM			RE	IM
.010	.002	.821	-1.336	-0.490	1.423	-160	.064	.792	1.437	.496	1.521	19	
.050	-0.157	.896	-0.661	-0.285	.720	-157	-0.135	.885	.978	.433	1.070	24	
.100	-0.217	.925	-0.734	-0.588	.940	-141	-0.185	.909	.849	.673	1.083	38	
.200	-0.257	.944	-0.566	-1.074	1.214	-118	-0.247	.938	.608	1.233	1.374	64	
.300	-0.293	.961	-1.138	-1.765	1.770	-85	-0.285	.956	-0.048	1.690	1.691	92	
.400	-0.329	.979	1.462	-2.225	2.662	-57	-0.319	.973	-1.291	2.051	2.424	122	
.450	-0.307	.968	2.104	-1.836	2.792	-41	-0.296	.962	-1.683	1.754	2.431	134	
.500	-0.270	.950	2.333	-1.416	2.730	-31	-0.258	.944	-2.112	1.399	2.533	146	
.550	-0.229	.930	2.577	-1.087	2.797	-23	-0.220	.925	-2.314	1.165	2.591	153	
.600	-0.193	.913	2.747	-0.745	2.846	-15	-0.179	.906	-2.586	.843	2.720	162	
.650	-0.161	.898	2.967	-0.489	3.007	-9	-0.142	.888	-2.869	.654	2.943	167	
.700	-0.126	.882	2.956	-0.230	2.965	-4	-0.104	.870	-3.307	.354	3.326	174	
.725	-0.106	.872	3.445	-0.194	3.451	-3	-0.081	.859	-3.571	.248	3.580	176	
.750	-0.061	.851	6.850	-0.178	6.853	-1	.017	.814	-7.104	.136	7.105	179	
.775	-0.080	.860	4.901	.086	4.901	1	-0.045	.843	-4.696	-0.106	4.698	181	
.800	-0.052	.847	3.740	.440	3.766	7	-0.029	.835	-3.638	-0.338	3.654	185	
.850	-0.013	.829	2.224	.501	2.280	13	-0.000	.822	-2.121	-0.483	2.175	193	
.900	.024	.811	1.194	.429	1.268	20	.036	.805	-1.329	-0.666	1.408	199	
.950	.071	.789	.455	.246	.517	28	.041	.784	-0.607	-0.296	.675	206	

TABLE 1.11

M = .850 F = 0 ALPHA = 0.00 KC = 1.41
 DELTA = 0.00 MC = .745
 C = 1.5 NC = .0358

X/C	CP +	UPPERSIDE				LOWERSIDE			
		M +	DCP +		DCP -	CP -	M -	DCP -	
			RE	IM				RE	IM
.010	.043	.829	2.731	0.0	.042	.820	-2.654	0.0	
.050	-.134	.914	1.914	0.0	-.130	.914	-1.745	0.0	
.100	-.180	.938	1.451	0.0	-.175	.936	-1.484	0.0	
.200	-.254	.976	1.499	0.0	-.264	.981	-1.585	0.0	
.300	-.304	1.001	1.710	0.0	-.317	1.008	-1.948	0.0	
.400	-.375	1.038	2.444	0.0	-.345	1.043	-2.559	0.0	
.450	-.340	1.020	3.705	0.0	-.362	1.031	-4.049	0.0	
.500	-.283	.990	4.794	0.0	-.282	.990	-5.042	0.0	
.550	-.237	.967	1.433	0.0	-.236	.967	-2.062	0.0	
.600	-.191	.944	1.984	0.0	-.190	.943	-1.986	0.0	
.650	-.152	.925	2.253	0.0	-.147	.922	-2.234	0.0	
.700	-.115	.906	2.654	0.0	-.105	.901	-2.674	0.0	
.725	-.100	.899	3.094	0.0	-.082	.890	-2.884	0.0	
.750	-.090	.894	4.660	0.0	.011	.845	-7.105	0.0	
.775	-.065	.882	4.049	0.0	-.047	.873	-3.877	0.0	
.800	-.039	.869	2.884	0.0	-.029	.864	-2.922	0.0	
.850	0.000	.850	1.690	0.0	.007	.847	-1.680	0.0	
.900	.017	.832	.966	0.0	.044	.829	-.974	0.0	
.950	.082	.810	.439	0.0	.047	.808	-.401	0.0	

TABLE 1.12

RUNNO 40916

$* = .853$ $F = 30.0$ $\text{ALPHA} = 0$
 $P_v = 1.425$ $\text{DELTA} = .16$
 $\text{REF} = 2.40E6$ $K = .060$ $C = 1.10$
 $S = 3302.42$

$\text{RE} = 1.119$ $\text{IM} = -0.278$ $\text{Re} = .2887$ $\text{II} = .0284$
 $\text{IC} = .732$ $\text{IC} = -.029$ $\text{IC} = .0393$ $\text{II} = .0156$

UPPERSIDE										LOWERSIDE									
X/C	CP+	M+	RE	IM	MOD	RG	DCP+	CP-	M-	RE	IM	MOD	ARG	DCP+	DCP-	DCP-			
.010	.015	.845	.292	-1.137	1.174	-76	.104	.803	-0.340	1.212	1.258	106							
.050	-0.156	.929	.153	-0.602	.621	-76	-0.107	.907	-0.373	.867	.944	113							
.100	-0.223	.961	.343	-0.737	.813	-65	-0.166	.937	-0.507	.867	1.005	120							
.200	-0.273	.988	.621	-0.843	1.047	-54	-0.244	.976	-0.828	.979	1.282	130							
.300	-0.321	1.013	.998	-1.951	1.379	-44	-0.296	1.002	-1.155	.998	1.526	139							
.400	-0.392	1.050	1.721	-1.059	2.021	-32	-0.354	1.033	-2.351	1.311	2.691	151							
.450	-0.377	1.042	4.088	-1.770	4.454	-23	-0.329	1.019	-3.773	1.312	3.995	161							
.500	-0.311	1.008	4.276	-0.332	4.289	-4	-0.265	.986	-2.161	.170	2.167	176							
.550	-0.243	.972	1.684	.334	1.913	10	-0.221	.964	-2.149	.090	2.151	178							
.600	-0.198	.951	1.975	.236	1.989	7	-0.174	.941	-2.265	.023	2.265	179							
.650	-0.160	.932	2.193	.161	2.199	4	-0.133	.926	-2.466	-0.047	2.466	181							
.700	-0.125	.914	2.384	-0.037	2.384	-1	-0.088	.898	-2.804	-0.114	2.807	182							
.725	-0.106	.905	2.837	-0.000	2.837	-0	-0.068	.888	-3.028	-0.141	3.031	183							
.750	-0.064	.884	5.195	.66	5.237	7	-0.020	.844	-5.510	1.582	5.733	164							
.775	-0.086	.892	4.426	.463	4.453	6	-0.026	.867	-4.063	-0.228	4.089	183							
.800	-0.052	.878	3.235	.578	3.286	10	-0.013	.860	-3.114	-0.300	3.128	185							
.850	-0.007	.856	1.812	.363	1.847	11	.014	.847	-1.796	-0.164	1.804	185							
.900	-0.034	.836	.955	.175	.971	10	.047	.831	-1.063	-0.177	1.077	189							
.950	.082	.813	.360	.040	.362	6	.092	.810	-0.465	-0.081	.472	190							

TABLE 1.13

RUNNO 40806

M = .854 F = 120₁₀ ALPHA = 0
 P0 = 10479 DELTA = .02
 HE = 2.41E6 K = .240 C = 1.05
 Q = .3320.06

KC= .797 IM= -.0.551 RQ= .3814 IM= .0651
 NC= .923 IM= -.0.147 NC= .0475 IM= .0146

X/C	CP+	UPPERSIDE				LOWERSIDE				DCP-		
		M+	DCP+	DCP+	CP-	M-	DCP+	MOD	AR8		MOD	AR8
.010	.019	.844	-1.224	.262	1.252	-192	.094	.808	1.220	-0.280	1.251	341
.050	-0.152	.929	-0.851	.161	.875	-196	.014	.910	.906	-0.116	.913	355
.100	-0.214	.960	-0.891	.065	.893	-184	.0169	.937	.989	.039	.990	3
.200	-0.267	.986	-1.213	-0.339	1.260	-164	.0245	.975	1.116	.633	1.283	31
.300	-0.314	1.011	-1.354	-1.330	1.897	-136	.0301	1.004	1.008	1.498	1.805	56
.400	-0.372	1.041	-0.325	-3.083	3.100	-96	.0354	1.032	-0.250	3.063	3.073	95
.450	-0.367	1.038	1.399	-4.719	4.922	-73	.0342	1.026	-1.513	4.335	4.592	102
.500	-0.330	1.019	3.214	-5.616	6.300	-59	.0280	.993	-3.476	2.969	4.571	140
.550	-0.236	.971	3.841	-1.564	4.147	-22	.0220	.963	-3.243	1.189	3.454	166
.600	-0.190	.966	3.538	-0.633	3.594	-10	.0178	.942	-3.274	.679	3.303	161
.650	-0.156	.930	3.489	-0.367	3.508	-6	.0136	.921	-3.374	.606	3.412	17
.700	-0.124	.915	3.485	-0.060	3.486	-1	.0093	.899	-3.587	.185	3.591	177
.725	-0.102	.903	3.056	-0.016	3.856	-0	.0074	.890	-3.860	.089	3.801	177
.750	-0.044	.875	7.724	.194	7.726	1	.021	.843	-7.010	-0.283	7.015	185
.775	-0.079	.893	5.129	.229	5.134	3	.0031	.869	-4.597	-0.276	4.605	182
.800	-0.051	.879	3.946	.589	3.990	8	.0018	.862	-3.637	-0.516	3.673	188
.850	-0.008	.857	2.246	.614	2.329	15	.012	.848	-2.116	-0.386	2.196	195
.900	.032	.838	1.032	.510	1.033	22	.048	.832	-1.260	-0.570	1.303	20
.950	.082	.814	.467	.261	.535	29	.086	.811	-0.526	-0.348	.629	21

TABLE 1.14

 $M = .875$ $F = 0$

$\text{ALPHA} = 0.00 \quad KC = 1.57$
 $\text{DELTA} = 0.00 \quad MC = 1.000$
 $C = 1.5 \quad NC = .0336$

UPPERSIDE

LOWERSIDE

X/C	CP +	M +	DCP +		CP -	M -	DCP -	
			RE	IM			RE	IM
.010	.069	.840	1.948	0.0	.088	.831	-1.948	0.0
.050	-.114	.933	1.317	0.0	-.109	.930	-1.337	0.0
.100	-.163	.958	.955	0.0	-.160	.957	-.993	0.0
.200	-.251	1.004	.897	0.0	-.256	1.007	-.974	0.0
.300	-.318	1.040	1.203	0.0	-.325	1.044	-1.298	0.0
.400	-.395	1.082	1.146	0.0	-.404	1.087	-1.260	0.0
.450	-.435	1.104	1.356	0.0	-.435	1.104	-1.585	0.0
.500	-.468	1.123	5.118	0.0	-.471	1.125	-5.290	0.0
.550	-.408	1.089	6.551	0.0	-.384	1.076	-6.761	0.0
.600	-.166	.960	7.640	0.0	-.163	.958	-7.888	0.0
.650	-.124	.938	5.882	0.0	-.119	.936	-5.233	0.0
.700	-.094	.923	2.311	0.0	-.081	.916	-2.406	0.0
.725	-.081	.916	2.483	0.0	-.062	.908	-2.406	0.0
.750	-.075	.913	4.106	0.0	-.029	.860	-6.436	0.0
.775	-.051	.901	3.648	0.0	-.029	.890	-3.304	0.0
.800	-.028	.889	2.654	0.0	-.011	.881	-2.502	0.0
.850	.013	.868	1.508	0.0	.022	.864	-1.528	0.0
.900	.049	.850	.802	0.0	.058	.846	-.802	0.0
.950	.094	.828	.362	0.0	.100	.825	-.286	0.0

TABLE 1.15

RUNNO 40907

$M = .877 \quad F = 30.0 \quad \text{ALPHAM} = 0$
 $P0 = 10425 \quad \text{DELTAM} = .15$
 $RE = 2.43E6 \quad KM = .039 \quad C = 1.13$
 $Q = 3403.23$

RE	IM	RE	IM		
1.166	-0.397	2719	.0604	X5 = 1.375E-3	0
.866	-0.063	RCR	.0366	X6 = 1.395E-3	0

X/C	CP+	M+	UPPERSIDE		CP-	M-	LOWERSIDE	
			DCP+	DCP+			DCP+	DCP+
.010	.048	.851	.071	.0024	.027	-.05	.015	-.0084
.050	-.130	.942	.015	-.0425	.426	-.88	-.091	.926
.100	-.195	.976	.117	-.0464	.479	-.76	-.0191	.957
.200	-.263	1.011	.206	-.0516	.556	-.68	-.0242	1.004
.300	-.334	1.050	.355	-.0778	.855	-.65	-.0308	1.040
.400	-.406	1.089	.521	-.0832	.981	-.58	-.0386	1.063
.450	-.450	1.114	.656	-.0857	1.000	-.53	-.0426	1.105
.500	-.476	1.129	1.210	-.1040	1.596	-.41	-.0364	1.071
.550	-.351	1.059	7.760	-.5.067	9.257	-.33	-.0291	1.031
.600	-.262	1.011	7.010	-.3.794	6.683	-.26	-.0178	.971
.650	-.154	.955	3.871	-.199	3.076	-.3	-.0.14	.937
.700	-.100	.927	2.265	-.567	2.335	-.14	-.0.071	.915
.725	-.082	.917	2.360	-.680	2.629	-.13	-.0.098	.905
.750	-.048	.900	4.891	1.172	5.029	-.13	-.0.036	.861
.775	-.063	.908	4.125	1.008	4.246	-.14	-.0.000	.884
.800	-.035	.894	3.046	-.947	3.190	-.17	-.0.003	.878
.850	.007	.872	1.386	-.590	1.706	-.19	-.0.020	.864
.900	.046	.851	.863	-.304	.934	-.19	-.0.002	.848
.950	.094	.828	-.384	-.100	.370	-.16	-.0.004	.827

TABLE 1.16

RUNNO 40807

M = .879 F = 120.0 ALPHA = 0
 P0 = 10474 DELTA = .01
 R2 = 2.44E6 K = .234 C = 1.08
 Q = 3426.23

KC = .579	RE	IM	RE	IM
MC = .757	-0.479	RC = .3998	.0592	
		NC = .0552	.0148	

X/C	CP+	M+	UPPERSIDE				LOWERSIDE				DCP-	
			RE		IM		RE		IM			
			DCP+	DCP+	DCP+	DCP+	DCP-	DCP-	DCP-	DCP-		
.010	.052	.852	-0.375	.422	.564	-229	.118	.82	.393	-1.441	.591	
.050	-0.129	.945	-0.146	.213	.258	-236	-0.096	.928	.270	-0.308	.410	
.100	-0.194	.979	-0.176	.213	.276	-230	-0.152	.958	.284	-1.312	.421	
.200	-0.262	1.015	-0.216	.192	.289	-222	-0.243	1.006	.415	-0.312	.519	
.300	-0.330	1.051	-0.336	.231	.408	-214	-0.311	1.042	.683	-0.228	.720	
.400	-0.406	1.093	-0.669	.187	.695	-196	-0.385	1.083	.858	-0.087	.862	
.450	-0.445	1.115	-0.795	.078	.799	-186	-0.424	1.104	1.211	.33	.354	
.500	-0.467	1.128	-1.389	-0.752	1.579	-152	-0.363	1.071	.179	4.753	1.255	
.550	-0.356	1.065	-3.250	-6.962	7.683	-115	-0.292	1.032	.577	7.526	.578	
.600	-0.244	1.005	1.224	-7.095	7.200	-80	-0.193	.979	-3.824	4.949	.625	
.650	-0.148	.955	4.090	-2.598	4.846	-32	-0.113	.94	-4.577	1.605	4.850	
.700	-0.103	.931	4.239	-0.825	4.318	-11	-0.073	.917	-4.569	.486	4.594	
.725	-0.083	.921	4.625	-0.489	4.651	-6	-0.054	.907	-4.564	.271	4.572	
.750	-0.025	.891	8.368	-0.211	8.371	-1	-0.038	.860	-7.141	.059	7.141	
.775	-0.064	.911	5.768	-0.015	5.768	-0	-0.013	.886	-5.277	-0.203	5.281	
.800	-0.037	.898	4.482	.472	4.506	6	-0.000	.880	-4.239	-0.463	4.264	
.850	.005	.876	2.628	.571	2.690	12	.026	.866	-2.490	-0.631	2.569	
.900	.045	.856	1.391	.496	1.477	20	.060	.849	-1.480	-0.626	1.607	
.950	.092	.832	.534	.269	.598	27	.11	.829	-0.657	-0.398	.768	

TABLE 1.17

M = .960

F = 0

ALPHA = 0.00 KC = .07
 DELTA = 0.00 MC = -.163
 C = 1.5 NC = -.0219

X/C	CP +	M +	UPPERSIDE				LOWERSIDE				DCP -	
			RE		IM		RE		IM			
			DCP +	DCP +	DCP -	DCP -	DCP -	DCP -	DCP -	DCP -		
.010	.178	.861	.038	0.0	.217	.839	-.152	0.0				
.050	-.007	.964	0.000	0.0	.013	.953	-.114	0.0				
.100	-.034	.982	-.038	0.0	-.032	.978	-.116	0.0				
.200	-.175	1.062	-.019	0.0	-.127	1.033	-.133	0.0				
.300	-.219	1.089	-.057	0.0	-.219	1.049	-.114	0.0				
.400	-.305	1.142	-.057	0.0	-.304	1.141	-.133	0.0				
.450	-.346	1.168	-.034	0.0	-.362	1.166	-.133	0.0				
.500	-.381	1.191	-.076	0.0	-.378	1.189	-.133	0.0				
.550	-.405	1.207	-.057	0.0	-.407	1.208	-.133	0.0				
.600	-.421	1.218	-.057	0.0	-.425	1.220	-.133	0.0				
.650	-.435	1.227	-.038	0.0	-.439	1.230	-.152	0.0				
.700	-.447	1.235	-.034	0.0	-.450	1.237	-.152	0.0				
.725	-.448	1.236	-.057	0.0	-.456	1.242	-.171	0.0				
.750	-.466	1.262	.744	0.0	-.484	1.193	-.167	0.0				
.775	-.471	1.252	3.094	0.0	-.482	1.232	-.266	0.0				
.800	-.463	1.266	2.560	0.0	-.442	1.232	-.189	0.0				
.850	-.212	1.084	.034	0.0	-.374	1.186	2.081	0.0				
.900	-.013	.967	.955	0.0	-.098	.993	.802	0.0				
.950	.070	.921	1.146	0.0	.053	.930	.210	0.0				

RUNNO 40911

TABLE 1.18

$M = .966 \quad F = 30.0 \quad \text{ALPHA} = 0$
 $P_0 = 10472 \quad \text{DELTAE} = .18$
 $RE = 2.63E6 \quad K = .054 \quad C_m = 1.03$
 $Q = 3759.58$

RE	IM	RE	IM
KC = .173	.083	RC = .1510	.0932
MC = .178	.108	NC = .0104	.0203

X/C	CP+	UPPERSIDE				LOWERSIDE				DCP-	
		RE		IM		MOD		ARG			
		CP+	DCP+	CP+	DCP+	CP-	DCP-	CP-	DCP-		
.010	.171	.870	.016	.0.024	.029	.56	.229	.838	-.0.038	.834	
.050	-0.013	.973	.004	-.0.019	.019	-.78	.014	.959	-.0.027	.017	
.100	-0.061	1.001	.003	-.0.014	.014	-.79	-.0.037	.988	-.0.018	.008	
.200	-0.125	1.039	-0.020	.005	.021	-.195	-.0.135	1.046	-.0.014	-0.005	
.300	-0.236	1.106	.003	-.0.005	.006	-.59	-.0.226	1.102	-.0.019	.085	
.400	-0.313	1.155	.013	-.0.019	.023	-.55	-.0.305	1.151	-.0.011	.012	
.450	-0.354	1.181	.017	-.0.024	.029	-.54	-.0.348	1.179	-.0.040	.020	
.500	-0.388	1.204	.017	-.0.015	.023	-.40	-.0.376	1.197	-.0.025	.028	
.550	-0.412	1.220	.025	-.0.023	.034	-.42	-.0.404	1.216	-.0.030	.001	
.600	-0.435	1.232	.023	-.0.019	.030	-.40	-.0.422	1.228	-.0.036	.019	
.650	-0.448	1.245	.002	-.0.010	.011	-.80	-.0.437	1.239	-.0.033	.035	
.700	-0.466	1.253	.013	-.0.023	.027	-.61	-.0.447	1.245	-.0.049	.017	
.725	-0.465	1.257	.026	-.0.029	.038	-.49	-.0.452	1.249	-.0.064	.085	
.750	-0.456	1.250	1.498	-.0.185	1.509	-.7	-.0.420	1.227	-1.931	.729	
.775	-0.488	1.273	4.594	.297	4.604	4	-.0.418	1.226	-.0.874	-0.557	
.800	-0.476	1.264	3.822	.419	3.845	6	-.0.416	1.225	-4.717	-0.659	
.850	-0.169	1.065	-2.897	1.024	3.072	-199	-.0.246	1.114	.300	-2.052	
.900	-0.012	.973	.833	.803	1.158	44	-.0.023	.980	.549	-0.785	
.950	.057	.934	1.307	.009	1.307	0	-.003	.931	.584	-0.138	

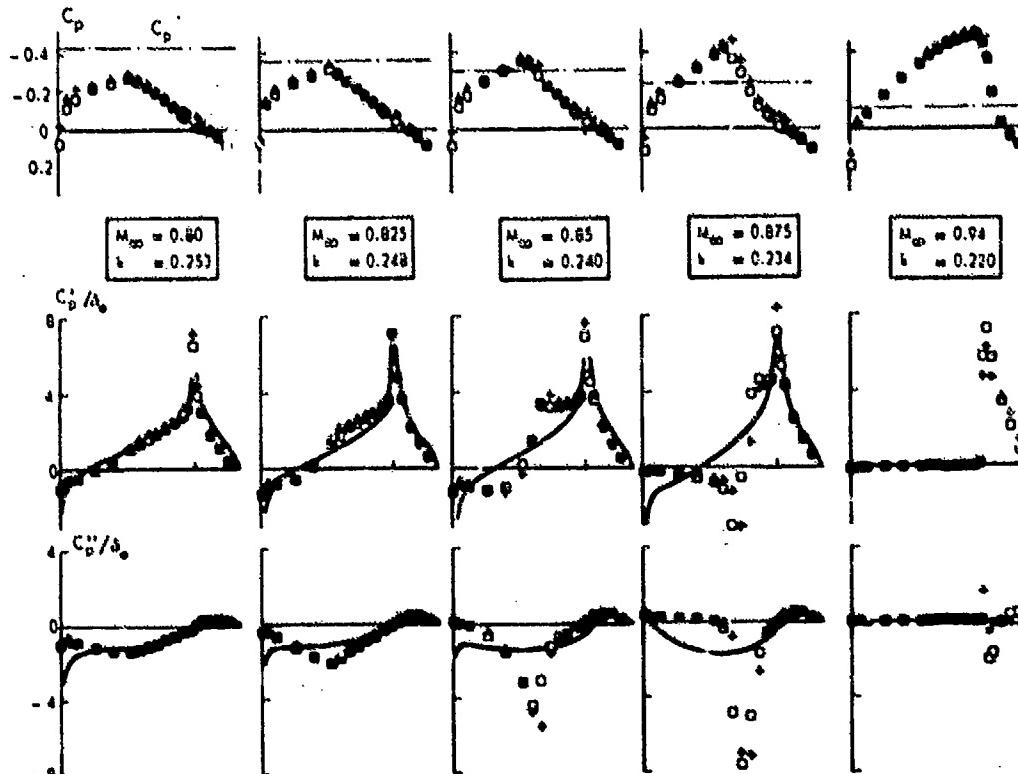
NACA 64A006 AIRFOIL

 $\alpha_m = 0 \quad \delta_m = 0$

EXP. | + UPPER SURFACE □ LOWER SURFACE

AMPLITUDE 10 DEG

— THIN-AIRFOIL THEORY

Fig. 1.1 Development of mean steady and unsteady pressure distributions with Mach number ($f = 120$ Hz)

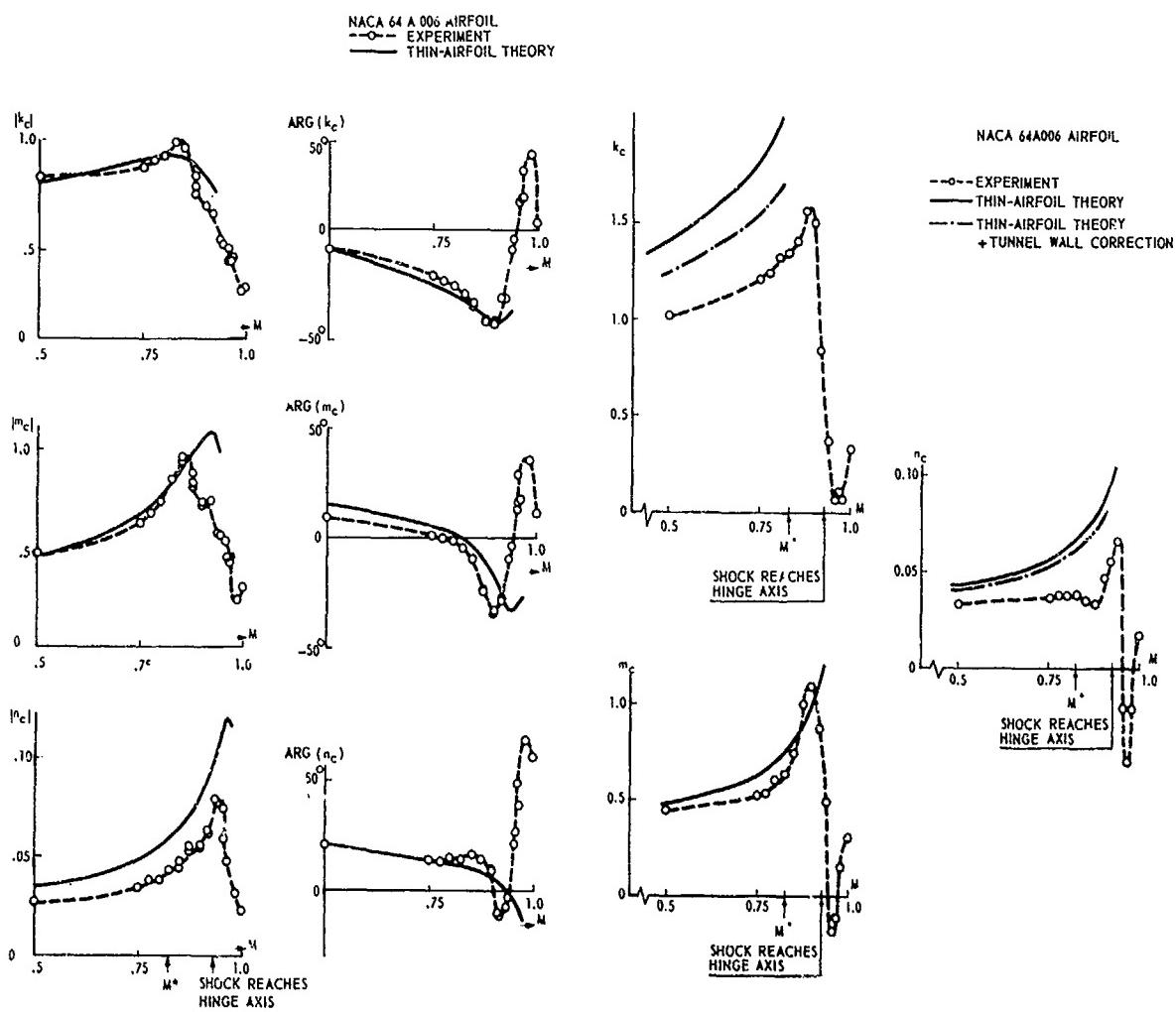


Fig. 1.2 Unsteady aerodynamic coefficients as a function of Mach number ($f = 120$ Hz)

Fig. 1.3 Steady aerodynamic derivatives as a function of Mach number

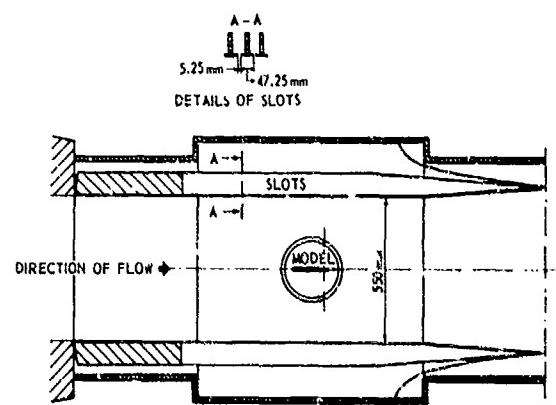


Fig. 1.4 Transonic test section of the NLR Pilot Tunnel

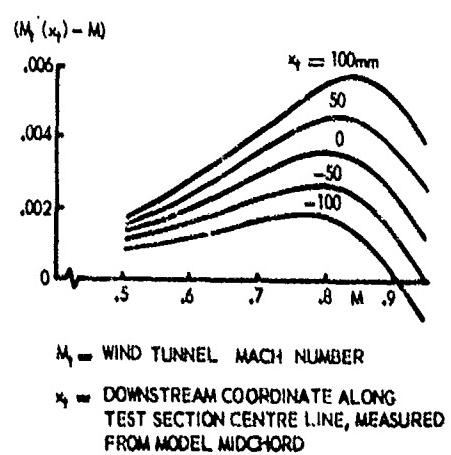


Fig. 1.5 Mach number distribution in NLR Pilot Tunnel test section

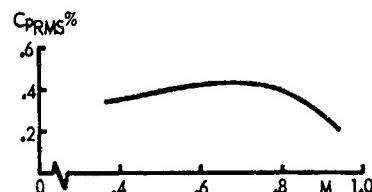


Fig. 1.6 Noise level in NLR Pilot Tunnel test section

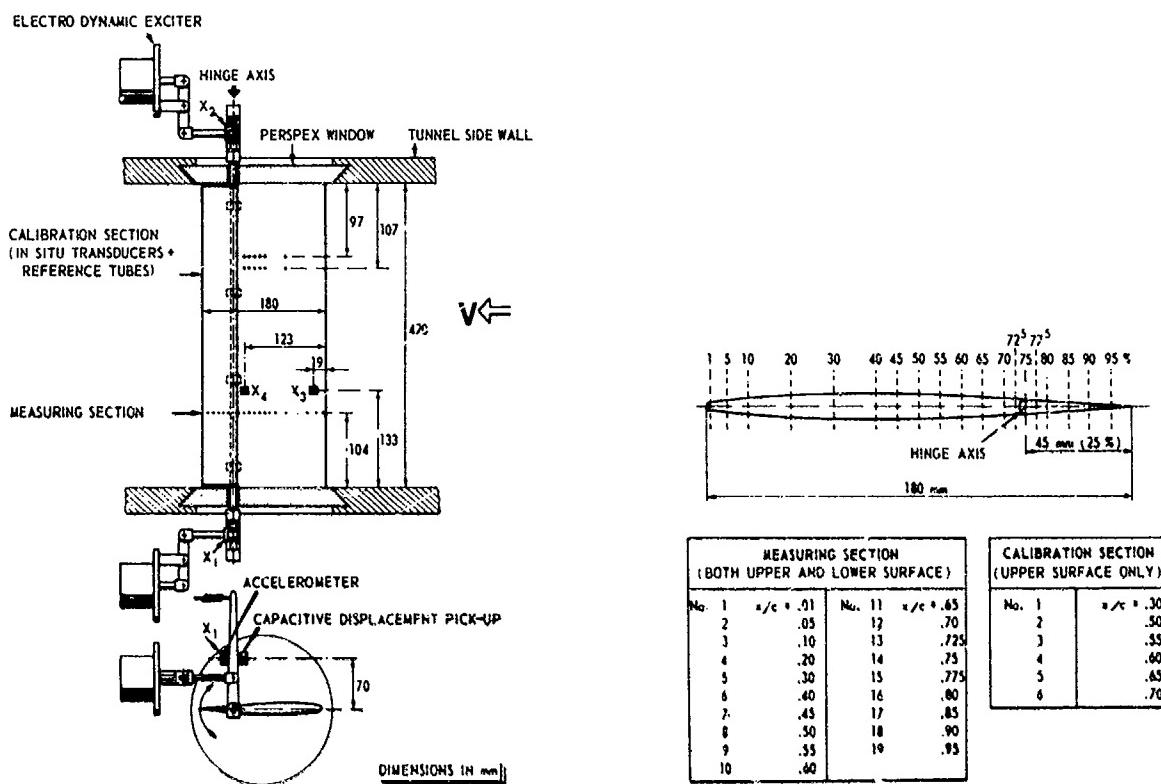


Fig. 1.7 Test set-up and instrumentation of the NACA 64A006 airfoil with flap

Fig. 1.8 Location of pressure orifices on the NACA 64A006 airfoil with flap

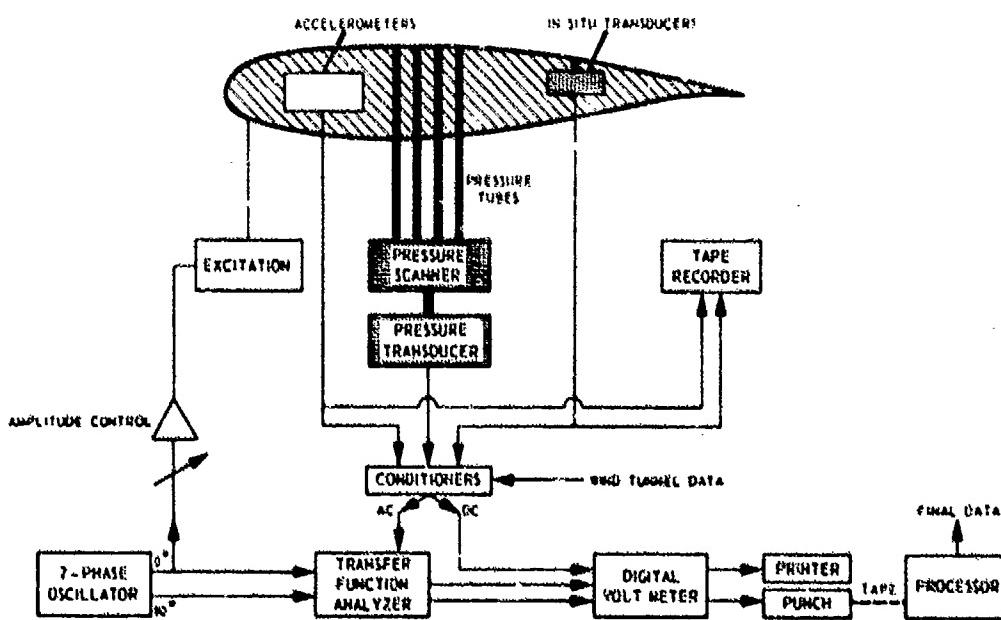


Fig. 1.9 Block diagram of measuring equipment

DATA SET 2

NACA 64A010 (NASA AMBS MODEL) OSCILLATORY PITCHING

by

Sanford S. Davis, NASA Ames

INTRODUCTION AND DISCUSSION

The test program on the oscillating NACA 64A010 airfoil was designed to expand the existing unsteady aerodynamic test envelope to a higher Reynolds number and more diverse flow conditions. The data base for this airfoil, as reported in Ref. 2.1, contains 114 different combinations of Mach number, Reynolds number, mean angle of attack, oscillation frequency, and motion mode. A subset of 66 runs corresponds to the motion of pitching about a nominal axis at 0.25c. The purpose of this Data Set is to present the matrix of test conditions corresponding to these 66 runs, to tabulate numerical data belonging to the ten AGARD CT Cases supplemented by a shock-stall case (SSC) of special interest, and to present an overview of certain parametric variations of the data. The data should be useful in ascertaining the performance of those numerical codes that predict unsteady transonic flows with shock-wave boundary-layer interactions.

Each combination of motion mode and the five input parameters M , c_m , Re , α_0 , and k are identified with a unique number - the dynamic index (DI). The output was the measured instantaneous chordwise pressure distribution on the airfoil. These data were digitized and processed on-line (Ref. 2.2) into a form that was suitable for interpretation and analysis. Subsequent off-line processing converted the data into the conventional normalized quantities presented in this Data Set. The notation generally follows that advocated as the AGARD standard. The nomenclature used here and an explanation of the table headings are included in Section 12 of this Data Set.

The following processed data are included for each of the AGARD CT Cases:

- A. Steady upper and lower surface pressure distributions.
- B. Fundamental frequency upper and lower surface pressure distributions.
- C. Steady lift and moment coefficients.
- D. Fundamental frequency lift and moment coefficients.

The following detailed data are presented for AGARD CT Case 6 only:

- E. Instantaneous upper surface pressure distribution.
- F. Instantaneous lift and moment coefficients.

Some of the data have been presented and/or discussed in previous publications. Items A, B, C, and D were included in the tabulated and graphical data of Ref. 2.1. The data were compared among themselves and with theory in Refs. 2.3 to 2.6.

Table 2.1 presents a complete list of the entire test program in chronological order. Table 2.2 shows the subset of 66 DI's considered in this Data Set. A small subset of 10 DI's, designated in Ref. 2.7 as AGARD CT Cases and the extra shock-stall case (SSC), are identified in Table 2.3 along with the relevant flow parameters. A sketch of the oscillating airfoil test apparatus is shown in Fig. 2.1. The experimental arrangement is described in detail in Refs. 2.1 and 2.8.

Tabulated data for the AGARD CT Cases and the SSC are presented in varying detail in Tables 2.4 to 2.18. Table 2.4 shows the steady values and the fundamental frequency complex amplitudes of lift and moment. (Note that the real and imaginary parts of the complex numbers in Table 2.4 are identical to the single- and double-primed quantities in the standard AGARD notation.) The mean and fundamental frequency pressure distributions are tabulated in Tables 2.5 to 2.14 and 2.17. These data are taken directly from the microfiche records enclosed in Ref. 2.1. A more basic data set, representing the instantaneous load on the airfoil, is presented in Table 2.15 for CT Case 6. Along with these data, the fundamental frequency component of the lift and moment is included for comparison and reference. The most detailed data set, from which all the previous data were derived, is the instantaneous pressure distribution. These data are presented in Table 2.16 in the form of chordwise pressure distributions at 6° phase increments for CT Case 6. The value of phase shown at the head of each column may be correlated with the nondimensional time, or the load, by cross-checking with Table 2.15.

With these AGARD CT data, one should be able to verify in detail the predictive capability of all inviscid codes and those viscous codes that include mild shock-wave/boundary-layer interactions. In Ref. 2.6 CT Case 6 was thoroughly analyzed and, being selected for priority analysis in Ref. 2.7, should be the first transonic case to compute.

Some of the first harmonic data were investigated for parametric trends. These data are presented in graphical form in Figs. 2.2 to 2.5. Fig. 2.2 shows the effect of varying Mach number with other parameters held constant. As the steady shock wave develops (uppermost row), the unsteady pressure distribution evolves into the peaked distribution usually associated with transonic flow. Although the unsteady pressure drops at $M = 0.84$, compared to $M = 0.80$, one should not consider this to be a typical response with increasing velocity in the transonic speed range. The data in Fig. 2.2 are presented at a reduced frequency $k = 0.2$, which is high enough to reduce the shock motion considerably. The interaction

between frequency and shock strength may be such that this dramatic drop in peak loading would not occur at lower values of k . Unfortunately, data at other frequencies were not measured at $M = 0.84$ so cross-trends cannot be determined experimentally.

Figure 2.3 shows the effect of varying the oscillation amplitude with other parameters held constant. Following the conventional notation, the pressure data (output) is normalized by the oscillation amplitude (input) to indicate the linearity of the response. Data presented in Ref. 2.4 showed that the force coefficients were linear functions of c_0 , but the individual pressure data do not seem to follow this trend. The shock-wave excursions, being minimal at lower oscillation amplitudes, induce peaked unsteady pressure distributions. However, at higher oscillation amplitudes the increased shock motion affects a larger portion of the airfoil. The net result is a balance in the loads even though the individual distributions vary. It is expected that this trend holds at other oscillation frequencies.

Figure 2.4 shows the frequency variation with other parameters held constant. As reported in Ref. 2.4, the pressure peaks and leading edge loading all decrease with increasing frequency. The trend is smoothly varying for this transonic flow condition, but this may not hold true for other conditions, such as shock-induced separation. For further discussions, refer to Refs. 2.3 and 2.5.

Figure 2.5 shows that scale effect is quite minimal for this flow condition. Sublimation photographs indicate that transition occurs at the shock wave at $Re = 3.3 \times 10^6$, while leading edge transition was observed at $Re = 12.6 \times 10^6$. Even though the point of transition varies widely, the unsteady pressure distributions are similar over the entire Reynolds number range. This benign behavior should not be considered a general rule; airfoil geometry and other mean flow conditions may be important factors (see Ref. 2.5).

The complete unsteady pressure distribution is shown in Fig. 2.6 for CT Cases 4 and 6. Certain features are common at both low and high frequencies: pure sinusoidal motion upstream of the shock wave, severe harmonic distortion at the shock, and minimal response towards the trailing edge region. The distorted wave forms in the shock region are caused by the frequency-dependent shock motion. These pressure data can be considered typical of that induced by unseparated, transonic flow over an oscillating airfoil. Although harmonic distortion is evident over part of the airfoil, the forces and moments are almost pure sinusoids.

ADDENDUM - A SHOCK-STALL CASE (SSC)

The AGARD CT Cases for this configuration refer to mean flows without separation. A more severe challenge to computational methods is the case where the airfoil pitches about a steady flow condition that supports a stronger shock wave. Some data from DI 89, a case not included in the AGARD Series but specified in Table 2.3, is presented for analysis and computational verification.

The fundamental frequency and steady pressure distributions are tabulated in Table 2.17 and the instantaneous pressure distribution in Table 2.18. Figure 2.7 depicts the complete unsteady pressure distribution on the upper surface at two frequencies. There is much more harmonic distortion, and the contrast with Fig. 2.6 is striking. The low frequency data at the shock wave in Fig. 2.7 are 180° out of phase when compared with CT Case 4 in Fig. 2.6, and a strong unsteady response persists to the trailing edge. Unlike the unseparated flows of the CT Cases, these complex flows require full Navier-Stokes modeling to predict both the steady shock wave position and the subsequent time-dependent motion.

1 AIRFOIL

1.1 Designation	NACA 64A010 (NASA Ames Model)
1.2 Type of airfoil	Conventional - Laminar Flow
1.3 Geometry	Refer to Ref. 2.8 for theoretical profile
1.4 Design condition	
1.5 Additional remarks	
1.6 References on airfoil	Ref. 2.8

2 MODEL GEOMETRY

2.1 Chord length	0.50 m (19.69 in.)
2.2 Span	1.35 m (53.2 in.)
2.3 Actual model coordinates and accuracy of measurement	Refer to AGARD-AR-15G (Ref. 2.7)
2.4 Flap: hinge and gap details	None
2.5 Additional remarks	Model mounted between splitter plates - see Fig. 2.1
2.6 References on model	Refs. 2.1, 2.2, and 2.9

3 WIND TUNNEL

3.1 Designation	NASA Ames 11- X 11-Foot Transonic Wind Tunnel
3.2 Type of tunnel	Closed return, variable density
3.3 Test section dimensions	3.35 X 3.35 X 6.7 m (11 X 11 X 22 ft.)
3.4 Type of roof and floor	Baffled slot

3	WIND TUNNEL (Continued)	
3.5	Type of side walls	Same as 3.4
3.6	Ventilation geometry	1.78 cm (0.7 in.) slots, 24.4 cm (9.63 in.) slats. Open area ratio ~ 8% between splitters
3.7	Thickness of side wall boundary layer	Very thin due to splitters
3.8	Thickness of boundary layers at roof and floor	Approx. 7.6 cm (3 in.)
3.9	Method of measuring Mach number	Static taps on splitters, see Refs. 2.2 and 2.9
3.10	Uniformity of Mach number over test section	±0.002
3.11	Sources of levels of noise or turbulence in empty tunnel	Not investigated
3.12	Tunnel resonances	None noted
3.13	Additional remarks	
3.14	References on tunnel	Ref. 2.2 and 2.9
4	MODEL MOTION	
4.1	Mode of applied motion	Pitching nominally about 0.25c and 0.50c, also plunging
4.2	Range of amplitude	±0-2 deg; ±1 cm
4.3	Range of frequency	0-60 Hz
4.4	Method of application	Four graphite epoxy push-pull rods with differential motion of forward and aft pair, Fig. 2.1
4.5	Purity of applied motion	Pure sinusoids
4.6	Natural frequencies and normal modes of model	Lowest mode: torsion at 60 Hz
4.7	Static or dynamic elastic distortion during tests	Not measured
4.8	Additional remarks	
5	TEST CONDITIONS	
5.1	Tunnel height/model chord ratio	3.35 m/0.50 m = 6.7
5.2	Tunnel width/model chord ratio	1.35 m/0.50 m = 2.7 (between splitter plates)
5.3	Range of Mach number	0.5-0.85
5.4	Range of tunnel total pressure	50 kN/m ² - 235 kN/m ² (0.5-2.25 ATM)
5.5	Range of tunnel total temperature	290 K - 320 K
5.6	Range of model steady, or mean, incidence	0-4 deg
5.7	Definition of model incidence	Chord line relative to wind tunnel
5.8	Position of transition, if free	Limited transition studies were attempted using a sublimating material. At M = 0.5, $\alpha = 0$, irregular patterns were observed without a definitive transition point. At M = 0.8, $\alpha = 0$, $Re = 12.6 \times 10^6$ transition was observed at $x/c = 0.05$. At M = 0.8, $\alpha = 0$, $Re = 3.4 \times 10^6$ transition was observed at $x/c = 0.5$ (the shock wave).
5.9	Position and type of trip, if transition fixed	
5.10	For mixed flow, position of sonic boundary in relation to roof and floor	Not measured
5.11	Flow instabilities during tests	--
5.12	Additional remarks	--
5.13	References describing tests	--
6	MEASUREMENTS AND OBSERVATIONS	
6.1	Steady pressures for the mean conditions	
6.2	Steady pressures for small changes from the mean conditions	
6.3	Quasi-steady pressures	
6.4	Unsteady pressures	



6	MEASUREMENTS AND OBSERVATIONS (Continued)		
6.5	Steady forces for the mean conditions	measured directly integrated pressures	- ✓
6.6	Steady forces for small changes from the mean conditions	measured directly integrated pressures	- -
6.7	Quasi-steady forces	measured directly integrated pressures	- -
6.8	Unsteady forces	measured directly integrated pressures	- -
6.9	Measurement of actual motion at points on model		-
6.10	Observation or measurement of boundary layer properties		✓
6.11	Visualization of surface flow		✓
6.12	Visualization of shockwave movements		-
6.13	Additional remarks		-
7	INSTRUMENTATION		
7.1	Steady pressures		
7.1.1	Position of orifices spanwise and chordwise	Mid-span, 20 upper, 20 lower; see Table 2.5 for locations	
7.1.2	Type of measuring system	Pneumatic	
7.2	Unsteady pressures		
7.2.1	Position of orifices spanwise and chordwise	Mid-span, 20 upper, 20 lower, see Table 2.5 for locations	
7.2.2	Diameter of orifices	1.02 mm (0.040 in.)	
7.2.3	Type of measuring system	Strain-gauge-type miniature pressure transducers installed close to orifice with minimum cavities.	
7.2.4	Type of transducers	Kulite model XCQL-7A-093.	
7.2.5	Principle and accuracy of calibration	On-line calibrations. Up to 2% change in static sensitivity before and after run allowed	
7.3	Model motion		
7.3.1	Method of measurement	Motion of four push-pull rods with LVDT (reactive-type) transducers. Phase synchronism checked with wing-mounted accelerometers	
7.3.2	Accuracy	~ 1%	
7.4	Processing of unsteady measurements		
7.4.1	Method of acquiring and processing measurements	Real-time digitization with on-line calibration and diagnostics. Signal averaging over about 100 cycles to suppress random noise (if present). Variable sampling time adjusted to yield 60 data points per cycle.	
7.4.2	Type of analysis	On-line processing for frequency content of pressure distributions and comparisons with linear theory and other data.	
7.4.3	Unsteady pressure quantities obtained and accuracies achieved	Signal-averaged (essentially instantaneous) pressure distributions. Harmonic analysis of pressure distributions.	
7.4.4	Method of integration to obtain forces	Numerical quadratures (see Appendix A of Ref. 2.1)	
7.5	Additional remarks		
7.6	References on techniques	Ref. 2.2	
8	DATA PRESENTATION		
8.1	Test cases for which data could be made available	Tables 2.1 and 2.2	
8.2	Test cases for which data are included in this document	Table 2.3	
8.3	Steady pressures	Tables 2.5 to 2.14 and 2.17	
8.4	Quasi-steady or steady perturbation pressures	N/A	
8.5	Unsteady pressures	Tables 2.5 to 2.14 and 2.16 to 2.18	
8.6	Steady forces or moments	None	

8	DATA PRESENTATION (Continued)	
8.7	Quasi-steady or steady perturbation forces	N/A
8.8	Unsteady forces and moments	Tables 2.4 and 2.15
8.9	Other forms in which data could be made available if required	Magnetic tape
8.10	References giving other presentations of data	Refs. 2.1 to 2.6
9	COMMENTS ON DATA	
9.1	Accuracy	
9.1.1	Mach number	±0.002
9.1.2	Steady incidence	±0.05 deg.
9.1.3	Reduced frequency	±0.005
9.1.4	Steady pressure coefficients	1%
9.1.5	Steady pressure derivatives	N/A
9.1.6	Unsteady pressure coefficients	2%
9.2	Sensitivity to small changes of parameter	No evidence of undue sensitivity, see Figs. 2.2 to 2.5
9.3	Spanwise variations	Probably small
9.4	Nonlinearities	Depends on data set
9.5	Influence of tunnel total pressure	Minimal on model distortion
9.6	Wall interference corrections	No corrections made
9.7	Other relevant tests on <i>same</i> model	None
9.8	Relevant tests on other models of nominally the <i>same</i> aerofoil.	None
9.9	Any remarks relevant to comparison between experiment and theory	Ref. 2.4, 2.6
9.10	Additional remarks	
9.11	References on discussion of data	Refs. 2.1 to 2.6
10	PERSONAL CONTACT FOR FURTHER INFORMATION	
	Sanford Davis, Aerodynamics Division, NASA Ames Research Center, Moffett Field, CA 94035	
11	REFERENCES	
2.1	S. Davis and G. Malcolm	Experimental Unsteady Aerodynamics of Conventional and Supercritical Airfoils. NASA TM-81221, Aug. 1980.
2.2	S. Davis	Computer/Experiment Integration for Unsteady Aerodynamic Research. Int'l. Congress on Instrumentation in Aerospace Simulation Facilities, ICIAS '79 Record, Sept. 1979, pp. 237-250.
2.3	S. Davis and G. Malcolm	Unsteady Aerodynamics of Conventional and Supercritical Airfoils. AIAA Paper 80-734, Seattle, WA, May 1980.
2.4	S. Davis and G. Malcolm	Transonic Shock-Wave/Boundary-Layer Interactions on an Oscillating Airfoil. AIAA Journal, Vol. 18, No. 11, Nov. 1980, pp. 1306-1312.
2.5	S. Davis	Experimental Studies of Scale Effects on Oscillating Airfoils at Transonic Speeds. AGARD-CP-296, Feb. 1981, pp. 9-1 to 9-6.
2.6	W. Chyu, S. Davis and K. S. Chang	Calculation of Unsteady Transonic Flow over an Airfoil. AIAA Journal, Vol. 19, No. 6, June 1981, pp. 684-690.
2.7	S. R. Bland	AGARD Two-Dimensional Aeroelastic Configurations. AGARD-AR-156, Aug. 1979.
2.8	I. Abbott, and A. Von Doenhoff	Theory of Wing Sections. Dover Pub., New York, 1959.
2.9	G. Malcolm and S. Davis	New NASA-Ames Wind Tunnel Techniques for Studying Airplane Spin and Two-Dimensional Unsteady Aerodynamics. In Dynamic Stability Parameters. AGARD CP-235, Nov. 1978, pp. 3-1 to 3-12.

12 NOTATION AND EXPLANATION OF TABLES*

GENERAL NOTATION

C,c	chord of airfoil, m
DI	dynamic index, data identification number
f,FREQ	frequency, Hz
k,K	reduced (nondimensional) frequency, $\frac{wc}{2V}$
M	free-stream Mach number
Re,RE	Reynolds number (based on chord)
t	time, s
V	free-stream velocity, m/s
X,x	distance along airfoil, m
x/c	pitch axis position relative to leading edge
$\alpha(t)$	Instantaneous incidence, deg ($\alpha_m + \alpha_o \cos \omega t$)
α_m	mean incidence, deg
α_o	oscillatory pitch amplitude, deg
ω	radian frequency, rad/s (= $2\pi f$)

TABLE 2.4

c_L	steady lift, +ve up [c_L]
c_M	steady moment, +ve nose up about $0.25c$ [c_M]
$c_{L,\alpha}$	normalized complex amplitude of lift coefficient, +ve up, per radian [$c'_L/\alpha_o + ic''_L/\alpha_o$]
$c_{M,\alpha}$	normalized complex amplitude of moment coefficient, +ve noseup, about $0.25c$, per radian [$c'_M/\alpha_o + ic''_M/\alpha_o$]

TABLES 2.5 to 2.14 and 2.17

ALPHA	mean incidence, deg [α_m]
PTOT	total pressure, N/m ² [p_t]
PINF	static pressure, N/m ² [p_∞]
QINF	dynamic pressure, N/m ² [q]
CPU(CPL)	steady upper (lower) surface pressure coefficient [c_p]
CPU,A (CPL,A)	normalized complex amplitude of upper (lower) surface fundamental frequency pressure coefficient, per radian [$c'_p/\alpha_o + ic''_p/\alpha_o$]

TABLE 2.15

TAU	nondimensional time [$\tau = 2Vt/c$]
WT	phase angle re $\alpha(t)$ max [ωt]
ALPHA	oscillatory incidence [$\alpha_o \cos \omega t$]
CL UP	upper surface contribution to c_L
CL LO	lower surface contribution to c_L
CL	instantaneous lift coefficient [$c_L(t)$]
CLN=1	instantaneous value of fundamental frequency component of lift coefficient
CM UP	upper surface contribution to c_M
CM LO	lower surface contribution to c_M
CM	instantaneous moment coefficient, +ve noseup, about $0.25c$ [$c_M(t)$]
CMN=1	instantaneous value of fundamental frequency component of moment coefficient

TABLES 2.16, 2.18

PHASE	phase angle re $\alpha(t)$ max [ωt]
ALPHA	oscillatory incidence [$\alpha_o \cos(\omega t)$]
CP	instantaneous pressure coefficient [$c_p(t)$]

*Square-bracketed quantities indicate standard AGARD notation.

TABLE 2.1. DATA BASE FOR NACA 64A010 AIRFOIL

DI	M	α_m , deg	$Re \times 10^{-6}$	Motion	f, Hz	k
1	0.489	0.03	2.51	Plunging 0.35 cm (0.137 in.)	5.0	0.048
2	.489	.01	2.50	Pitching 0.94 deg about $x_a/c = .236$	20.8	.200
3	.488	.00	2.50	Pitching .95 deg about $x_a/c = .512$	20.8	.200
4	.489	.01	2.31	Plunging 1.01 cm (0.396 in.)	20.8	.200
5	.490	-.01	2.52	Pitching .96 deg about $x_a/c = .507$	26.0	.249
6	.490	-.01	2.52	Pitching .96 deg about $x_a/c = .238$	15.7	.151
7	.490	-.01	2.52	Pitching .96 deg about $x_a/c = .233$	10.4	.100
8	.490	-.01	2.52	Pitching .97 deg about $x_a/c = .230$	5.2	.050
9	.490	-.01	2.52	Pitching 1.01 deg about $x_a/c = .224$	2.6	.025
10	.490	-.01	2.52	Pitching 1.98 deg about $x_a/c = .249$	5.2	.050
11	.489	.00	2.51	Pitching 1.45 deg about $x_a/c = .250$	20.8	.200
12	.802	.00	3.38	Pitching .94 deg about $x_a/c = .232$	33.2	.200
13	.802	.00	3.38	Pitching 1.27 deg about $x_a/c = .431$	33.2	.200
14	.797	-.06	3.39	Plunging .89 cm (0.349 in.)	33.1	.201
15	.797	-.06	3.39	Pitching .95 deg about $x_a/c = .234$	41.3	.250
16	.795	.01	6.67	Pitching .96 deg about $x_a/c = .252$	33.3	.201
17	.795	.01	6.67	Pitching .98 deg about $x_a/c = .501$	33.3	.201
18	.795	.01	6.67	Plunging .38 cm (0.346 in.)	33.3	.201
19	.795	.01	6.67	Pitching 1.10 deg about $x_a/c = .505$	41.6	.251
20	.497	.04	5.03	Pitching .01 deg about $x_a/c = .046$	5.0	.047
21	.497	.04	5.03	Pitching .99 deg about $x_a/c = .257$	21.3	.201
22	.497	.04	5.03	Pitching 1.07 deg about $x_a/c = .504$	21.3	.201
23	.497	.04	5.03	Plunging 1.02 cm (0.400 in.)	21.3	.201
24	1.074	.00	6.58	Plunging .44 cm (0.173 in.)	5.0	.024
25	.497	1.98	5.00	Plunging .00 cm (0.000 in.)	5.0	.047
26	.502	-.22	9.98	Pitching .00 deg about $x_a/c = .150$	5.0	.046
27	.502	-.22	9.98	Pitching .24 deg about $x_a/c = .234$	10.8	.100
28	.502	-.22	9.98	Pitching .51 deg about $x_a/c = .269$	10.8	.100
29	.502	-.22	9.98	Pitching 1.02 deg about $x_a/c = .269$	10.8	.100
30	.499	-.21	9.90	Pitching .26 deg about $x_a/c = .277$	21.5	.201
31	.499	-.13	9.89	Pitching .50 deg about $x_a/c = .271$	21.5	.200
32	.499	-.13	9.89	Pitching 1.00 deg about $x_a/c = .269$	21.5	.200
33	.499	-.13	9.89	Pitching 2.01 deg about $x_a/c = .267$	21.5	.200
34	.499	-.13	9.89	Pitching 2.13 deg about $x_a/c = .503$	21.5	.200
35	.499	-.13	9.89	Pitching 1.06 deg about $x_a/c = .506$	21.5	.200
36	.499	-.13	9.89	Plunging 1.01 cm (0.399 in.)	21.5	.200
37	.499	-.13	9.89	Pitching 1.00 deg about $x_a/c = .252$	26.9	.251
38	.499	-.13	9.89	Pitching 1.07 deg about $x_a/c = .506$	26.9	.251
39	.499	-.13	9.89	Pitching 1.00 deg about $x_a/c = .250$	16.2	.151
40	.499	-.13	9.89	Plunging 1.01 cm (0.396 in.)	16.2	.151
41	.499	-.13	9.89	Plunging 1.02 cm (0.401 in.)	10.8	.101
42	.499	-.13	9.89	Plunging 1.03 cm (0.405 in.)	5.4	.050
43	.499	-.13	9.89	Pitching 1.02 deg about $x_a/c = .248$	5.4	.050
44	.499	-.13	9.89	Pitching 2.04 deg about $x_a/c = .245$	10.8	.101
45	.648	-.22	11.63	Pitching .97 deg about $x_a/c = .249$	27.8	.201
46	.744	-.22	12.31	Pitching 1.01 deg about $x_a/c = .248$	32.0	.201
47	.796	-.21	12.56	Pitching .30 deg about $x_a/c = .202$	17.1	.101
48	.796	-.21	12.56	Pitching .25 deg about $x_a/c = .234$	34.2	.201
49	.796	-.21	12.56	Pitching .51 deg about $x_a/c = .247$	17.1	.101
50	.796	-.21	12.56	Pitching .50 deg about $x_a/c = .248$	34.2	.201
51	.796	-.21	12.56	Pitching 1.03 deg about $x_a/c = .249$	4.2	.025
52	.796	-.21	12.56	Pitching 1.02 deg about $x_a/c = .246$	8.6	.051
53	.796	-.21	12.56	Pitching 1.02 deg about $x_a/c = .248$	17.2	.101
54	.796	-.21	12.56	Pitching 1.01 deg about $x_a/c = .254$	25.7	.151
55	.796	-.21	12.56	Pitching 1.01 deg about $x_a/c = .248$	34.4	.202
56	.796	-.21	12.56	Pitching 1.02 deg about $x_a/c = .248$	42.0	.247
57	.796	-.21	12.56	Pitching .99 deg about $x_a/c = .252$	51.5	.303
58	.796	-.21	12.56	Pitching 1.00 deg about $x_a/c = .502$	42.9	.252
59	.796	-.21	12.56	Pitching 1.09 deg about $x_a/c = .500$	34.4	.202
60	.796	-.21	12.56	Pitching 1.08 deg about $x_a/c = .502$	17.2	.101
61	.796	-.21	12.56	Pitching 1.09 deg about $x_a/c = .501$	8.6	.051
62	.796	-.21	12.56	Pitching 1.12 deg about $x_a/c = .499$	4.3	.025
63	.797	-.08	12.40	Pitching 1.95 deg about $x_a/c = .471$	34.3	.201
64	.797	-.08	12.40	Pitching 1.94 deg about $x_a/c = .231$	34.3	.201
65	.797	-.08	12.40	Pitching 2.00 deg about $x_a/c = .239$	17.2	.101
66	.797	-.08	12.40	Plunging 1.01 cm (0.396 in.)	34.3	.201
67	.797	-.08	12.40	Plunging 1.02 cm (0.401 in.)	25.8	.151
68	.797	-.08	12.40	Plunging 1.02 cm (0.400 in.)	17.4	.102
69	.797	-.08	12.40	Plunging 1.01 cm (0.400 in.)	8.6	.050
70	.797	-.08	12.40	Plunging 1.04 cm (0.409 in.)	4.3	.025
71	.842	.00	12.45	Pitching 1.01 deg about $x_a/c = .248$	36.4	.202
72	.842	-.22	12.63	Pitching 1.01 deg about $x_a/c = .247$	36.5	.202
73	.805	-.00	3.3	Pitching 1.01 deg about $x_a/c = .247$	25.1	.149
74	.805	-.00	3.34	Plunging .44 cm (0.173 in.)	5.0	.030
75	.805	-.00	3.34	Pitching 1.02 deg about $x_a/c = .248$	8.3	.049

TABLE 2.1. Continued.

DI	M	α_m^* deg	$R \times 10^{-6}$	Motion	f, Hz	k
76	0.805	0.00	3.34	Pitching 2.03 deg about $x_a/c = 0.248$	8.3	0.049
77	.805	.00	3.34	Pitching 2.00 deg about $x_a/c = .248$	33.3	.198
78	.794	.08	12.40	Pitching .64 deg about $x_a/c = .328$	10.0	.059
79	.782	4.00	12.01	Pitching .25 deg about $x_a/c = .232$	17.3	.102
80	.782	4.00	12.01	Pitching .25 deg about $x_a/c = .229$	34.7	.205
81	.782	4.00	12.01	Pitching .51 deg about $x_a/c = .244$	17.4	.103
82	.792	3.93	6.15	Pitching 1.01 deg about $x_a/c = .247$	34.3	.203
83	.793	4.01	6.18	Pitching 1.02 deg about $x_a/c = .248$	34.2	.202
84	.789	4.00	11.88	Pitching .51 deg about $x_a/c = .234$	34.9	.203
85	.789	4.00	11.88	Pitching 1.04 deg about $x_a/c = .246$	4.4	.026
86	.789	4.00	11.88	Pitching 1.03 deg about $x_a/c = .246$	8.8	.051
87	.789	4.00	11.88	Pitching 1.02 deg about $x_a/c = .248$	17.5	.102
88	.789	4.00	11.88	Pitching 1.01 deg about $x_a/c = .247$	26.3	.153
89	.789	4.00	11.88	Pitching 1.01 deg about $x_a/c = .249$	35.1	.204
90	.789	4.00	11.88	Pitching 1.01 deg about $x_a/c = .248$	43.9	.255
91	.789	4.00	11.88	Pitching 1.00 deg about $x_a/c = .248$	52.7	.306
92	.789	4.00	11.88	Pitching 1.08 deg about $x_a/c = .499$	35.2	.205
93	.789	4.00	11.88	Plunging .84 cm (0.330 in.)	35.2	.205
94	.789	4.00	11.88	Pitching 1.08 deg about $x_a/c = .501$	44.0	.256
95	.789	4.00	11.88	Pitching 2.00 deg about $x_a/c = .245$	17.6	.102
96	.741	4.03	11.22	Pitching 1.02 deg about $x_a/c = .246$	35.2	.215
97	.642	3.99	10.60	Pitching 1.01 deg about $x_a/c = .247$	28.8	.203
98	.504	4.00	10.20	Pitching 1.02 deg about $x_a/c = .249$	22.2	.199
99	.506	3.99	9.45	Pitching 1.09 deg about $x_a/c = .499$	22.0	.198
100	.506	3.99	9.45	Plunging 1.01 cm (0.397 in.)	22.0	.198
101	.506	3.99	9.45	Pitching 1.09 deg about $x_a/c = .302$	27.5	.247
102	.506	3.99	9.45	Pitching 2.14 deg about $x_a/c = .502$	27.5	.247
103	.790	4.00	11.72	Pitching 2.01 deg about $x_a/c = .243$	35.0	.203
104	.503	4.00	4.94	Pitching 1.01 deg about $x_a/c = .245$	21.6	.199
105	.503	4.00	4.94	Pitching 1.09 deg about $x_a/c = .499$	21.6	.199
106	.503	4.00	4.94	Plunging 1.02 cm (0.401 in.)	21.6	.199
107	.503	4.00	4.94	Pitching 1.08 deg about $x_a/c = .502$	26.9	.248
108	.642	3.78	5.92	Pitching 1.02 deg about $x_a/c = .250$	27.6	.203
109	.747	3.89	6.36	Pitching 1.02 deg about $x_a/c = .247$	31.0	.197
110	.797	4.01	6.30	Pitching 1.09 deg about $x_a/c = .500$	33.5	.201
111	.797	4.01	6.50	Plunging 1.01 cm (0.398 in.)	33.5	.201
112	.797	4.01	6.50	Pitching 1.08 deg about $x_a/c = .502$	42.0	.252
113	.848	3.89	6.59	Pitching 1.01 deg about $x_a/c = .248$	35.5	.201
114	.840	3.79	12.39	Pitching 1.01 deg about $x_a/c = .248$	36.3	.202

TABLE 2.2. DATA BASE FOR NACA 64A010 AIRFOIL, PITCHING OSCILLATION
ABOUT 0.25c NOMINAL, ARRANGED IN FREQUENCY SWEEPS

M	α_m^* deg	$R \times 10^{-6}$	α_0 deg	$k = 0.025$	$k = 0.05$	$k = 0.10$	$k = 0.15$	$k = 0.20$	$k = 0.25$	$k = 0.30$	Type of Flow
0.50	0.0	10	± 0.25			27		30			
.50	0.0	10	± 0.50			28		31			
.50	0.0	2.5	± 1	9	8	7	6	2			
.50	0.0	5	± 1					21			
.50	0.0	10	± 1		43	29	39	32	37		
.50	0.0	2.5	± 2		10			11			
.50	0.0	10	± 2		44			33			
.65	0.0	11.6	± 1				45				
.75	0.0	12.3	± 1				46				
.80	0.0	3.3	± 1		75		73	12	15		
.80	0.0	12.5	± 0.25					48			
.80	0.0	12.5	± 0.50		78	49		50			
.80	0.0	6.7	± 1					16			
.80	0.0	12.6	± 1	51	52	53	54	55	56	57	
.80	0.0	12.4	± 2			65		64			
.85	0.0	12.4	± 1					72			
.50	4.0	4.9	± 1					104			
.50	4.0	10.2	± 1					98			
.65	4.0	5.9	± 1					108			
.65	4.0	10.6	± 1					97			
.75	4.0	6.4	± 1					109			
.75	4.0	11.2	± 1					96			
.80	4.0	12	± 0.25			79		80			
.80	4.0	12	± 0.50			81		84			
.80	4.0	6.2	± 1					82			
.80	4.0	11.9	± 1	85	86	87	88	89	90	91	
.80	4.0	11.9	± 2			95		103			
.85	4.0	6.6	± 1					113			

TABLE 2.3. SELECTED NASA AMES TEST DATA ASSOCIATED WITH AGARD CT CASES AND THE SHOCK STALL CASE (SSC)

CT Case	DI	M	α_m	$Re \times 10^{-6}$	α_o	f	k	x_{α}/c
1	7	0.490	-0.01	2.52	0.96	10.4	0.100	0.233
2	29	0.502	-0.22	9.98	1.02	10.8	0.100	0.269
3	51	0.796	-0.21	12.56	1.03	4.2	0.025	0.249
4	52	0.796	-0.21	12.56	1.02	8.6	0.051	0.246
5	53	0.796	-0.21	12.56	1.02	17.2	0.101	0.248
6	55	0.796	-0.21	12.56	1.01	34.4	0.202	0.248
7	57	0.796	-0.21	12.56	0.99	51.5	0.303	0.252
8	49	0.796	-0.21	12.56	0.51	12.1	0.101	0.247
9	65	0.797	-0.08	12.40	2.00	17.2	0.101	0.239
10	12	0.802	0.00	3.38	0.94	33.2	0.200	0.232
SSC	89	0.789	4.00	11.88	1.01	35.1	0.204	0.249

TABLE 2.4. STEADY AND FUNDAMENTAL FREQUENCY LIFT AND MOMENT DATA FOR SELECTED CASES

Case	DI	Steady	Data	$C_{L,\alpha}$	$C_{M,\alpha}$
		C_L	C_m		
CT1	7	0.006	-0.002	6.139 - 1.149i	0.165 - 0.163i
CT2	29	0.016	0.001	6.163 - 1.036i	0.167 - 0.201i
CT3	51	-0.029	-0.003	9.316 - 1.378i	0.000 - 0.102i
CT4	52	-0.029	-0.003	8.622 - 2.479i	-0.005 - 0.232i
CT5	53	-0.029	-0.003	6.790 - 3.387i	-0.061 - 0.388i
CT6	55	-0.029	-0.003	4.887 - 2.521i	-0.189 - 0.653i
CT7	57	-0.029	-0.003	4.635 - .905i	-0.374 - 1.023i
CT8	49	-0.029	-0.003	6.795 - 3.403i	-0.195 - 0.314i
CT9	65	-0.018	-0.002	6.141 - 3.113i	-0.239 - 0.302i
CT10	12	0.009	-0.002	5.308 - 2.471i	-0.384 - 0.546i
SSC	89	0.531	0.001	9.349 - 0.406i	-2.068 + 0.198i

TABLE 2.5. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA FOR AGARD CT CASE NO. 1; DYNAMIC INDEX 7

WING MODEL: NACA 64A010, CHORD= 500 METERS

WING MOTION PITCHING 90 DEG ABOUT X/C = 203

DYNAMIC INDEX 7 STATIC INDEX 9

M	490	PTOT	50564	K	100
ALPHA	+ 01	QINF	7250	FREQ	10.4
RE	2.91E 06	PINF	43169		

.....UPPER SURFACE.....

STEADY DATA		UNSTEADY DATA			
CPU		CPU A			
X/C	CPU	X/C	REAL	IMAG	IMAG
030	.168	033	+11.722	3.045	12.111
042	.185	052	-9.409	2.104	9.650
061	.214	091	-7.293	1.655	7.572
142	.253	.140	-5.434	1.176	5.560
211	.292	209	-4.035	.725	4.100
243	.299	243	-4.296	.731	4.358
292	.313	339	-3.348	.446	3.401
341	.326	402	-3.254	.582	3.307
440	.319	440	-1.306	.633	2.084
487	.296	489	-1.194	.878	1.485
537	.281	628	-1.446	.345	.584
565	.197	684	-1.944	.023	1.944
634	.143	633	-1.412	.069	1.414
682	.116	682	-1.049	.018	1.029
733	.065	733	-0.860	.123	.946
763	.020	761	-0.702	.130	.715
827	.010	829	-0.370	.029	.271
874	.052	872	-0.560	.161	.583
926	.080	941	-1.12	.048	.121

.....LOWER SURFACE.....

STEADY DATA		UNSTEADY DATA			
CPU		CPU A			
X/C	CPU	X/C	REAL	IMAG	IMAG
030	.168	033	+11.722	3.045	12.111
042	.185	052	-9.409	2.104	9.650
061	.214	091	-7.293	1.655	7.572
142	.253	.140	-5.434	1.176	5.560
211	.292	209	-4.035	.725	4.100
243	.299	243	-4.296	.731	4.358
292	.313	339	-3.348	.446	3.401
341	.326	402	-3.254	.582	3.307
440	.319	440	-1.306	.633	2.084
487	.296	489	-1.194	.878	1.485
537	.281	628	-1.446	.345	.584
565	.197	684	-1.944	.023	1.944
634	.143	633	-1.412	.069	1.414
682	.116	682	-1.049	.018	1.029
733	.065	733	-0.860	.123	.946
763	.020	761	-0.702	.130	.715
827	.010	829	-0.370	.029	.271
874	.052	872	-0.560	.161	.583
926	.080	941	-1.12	.048	.121

TABLE 2.6. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 2; DYNAMIC INDEX 29

WING MODEL: NACA 64A010, CHORD= 500 METER

WING MOTION PITCHING 1 02 DEG ABOUT X/C. 26

DYNAMIC INDEX 29 STATIC INDEX 29

M	.502	PTOT	203152	K	10
ALPHA	- 22	QINF	30199	FREQ	10
RE	1 OCE 07	PINF	171000		

UPPER SURFACE								LOWER SURFACE								
STEADY DATA				UNSTEADY DATA				STEADY DATA				UNSTEADY DATA				
CPU		CPU, A		CPL		CPL, A		X/C		REAL		IMAG		MAG		PHAS
X/C	CPU	X/C	REAL	IMAG	MAG	PHASE	X/C	CPL	X/C	REAL	IMAG	MAG	PHAS			
.030	.136	.033	-10.116	2.659	10.459	165.29	.032	.034	.034	11.019	-2.959	11.410	+15.0			
.091	.177	.052	-7.608	1.994	7.865	165.33	.093	.142	.054	9.351	-2.296	9.629	+13.8			
.142	.223	.091	-6.377	1.434	6.536	171.34	.142	.227	.094	6.781	-1.585	6.964	+13.1			
.211	.253	.140	-5.231	1.181	5.362	67.28	.199	.246	.141	5.469	-1.172	5.593	+12.1			
.243	.265	.209	-4.369	.791	4.440	169.75	.244	.289	.200	4.541	-8.837	4.617	+10.4			
.292	.287	.243	-4.026	.679	4.083	170.44	.293	.298	.243	4.075	-8.692	4.133	+9.6			
.341	.304	.294	-3.810	.576	3.653	171.41	.341	.285	.293	3.177	-5.500	3.216	+8.9			
.399	.309	.402	-3.165	.364	3.186	173.45	.393	.294	.341	3.099	-3.367	3.123	+7.1			
.440	.300	.440	-2.363	.226	2.395	174.60	.440	.308	.394	2.647	-2.275	2.662	+5.9			
.487	.263	.488	-2.020	.109	2.023	176.93	.490	.276	.441	2.367	-1.164	2.393	+3.9			
.537	.226	.538	-1.723	.023	1.723	179.25	.537	.223	.490	2.014	-0.080	2.015	+2.2			
.585	.190	.584	-1.385	.027	1.385	-178.90	.583	.183	.582	1.434	.033	1.434	1.3			
.634	.137	.633	-1.188	.077	1.190	-176.32	.625	.148	.631	1.203	.062	1.204	2.9			
.682	.114	.682	.977	.108	.963	-173.72	.679	.111	.676	.979	.112	.986	6.5			
.733	.061	.733	.814	.137	.825	-170.48	.734	.067	.733	.759	.121	.769	9.0			
.827	.016	.781	.613	.160	.634	-165.39	.769	.016	.781	.597	.127	.611	11.9			
.874	.055	.829	.562	.170	.587	-163.15	.832	.018	.831	.410	.128	.430	17.3			
.924	.091	.972	.333	.148	.365	-158.06	.866	.077	.866	.316	.110	.335	19.1			
	.941	.097	.110	.147	.101	23	.941	.121	.923	.176	.087	.199	.259			

TABLE 2.7. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA FOR AGARD CT CASE NO. 3; DYNAMIC INDEX 51

WING MODEL: NACA 64A010, CHORD: 500 MILLIMETERS

WING MOTION PITCHING 1.03 DEG ABOUT X/C 24

DYNAMIC INDEX 51 STATIC INDEX 3

M	796	PTOT	203321	X	0
ALPHA	- .21	QINF	59395	FREQ	4
RE	1 30E-07	PINF	133912		

UPPER SURFACE							LOWER SURFACE						
STEADY DATA			UNSTEADY DATA				STEADY DATA			UNSTEADY DATA			
CPU		CPU A					CPU		CPU A				
X/C	CPU	X/C	REAL	IMAG	MAG	PHASE	X/C	CPU	X/C	REAL	IMAG	MAG	PHASE
0.00	- 006	0.02	-10.450	1.000	10.614	169.92	0.02	- 207	0.04	12.103	-3.329	12.328	-1.0
.001	- 193	0.02	-9.641	1.700	9.809	170.03	0.02	- 178	0.04	10.371	-1.980	10.540	-1.0
142	- 292	0.01	-8.528	1.479	8.653	170.17	142	- 316	0.04	8.826	-1.607	8.971	-1.0
211	- 378	140	-7.560	1.433	7.714	169.21	199	- 320	141	8.098	-1.510	8.237	-1.0
243	- 418	209	-6.812	1.192	6.915	170.08	244	- 457	200	7.605	-1.371	7.531	-1.0
262	- 481	243	-6.812	1.229	7.020	169.93	293	- 500	203	8.293	-1.113	8.391	-1.0
341	- 544	294	-6.732	1.247	6.846	169.52	341	- 536	293	8.256	-1.061	8.348	-1.0
369	- 639	403	-6.202	1.440	8.327	170.08	393	- 629	341	8.343	-1.149	8.446	-1.0
440	- 703	440	-6.717	1.477	8.842	170.40	440	- 713	364	8.184	-1.117	8.394	-1.0
487	- 564	480	-14.522	2.131	14.670	171.67	480	- 777	480	13.771	-3.269	13.957	-1.0
537	- 322	530	-2.658	-1.23	2.659	-177.38	537	- 234	642	791	-232	656	-22
545	- 250	584	392	-5.97	1.120	-29.30	583	- 253	631	-302	402	503	128
634	- 101	633	337	-3.09	9.15	-69.13	625	- 198	678	-360	341	602	127
642	- 132	733	-0.68	293	296	-100.76	670	- 137	733	-203	373	393	130
723	- 061	781	026	-2.27	229	-83.40	734	- 070	781	-177	306	273	130
827	- 041	829	082	-210	229	-73.61	789	- 008	831	-325	168	365	192
874	- 092	872	108	-144	100	-93.02	832	- 043	868	-212	118	242	191
924	- 141	941	045	-080	063	-60.87	896	- 113	923	-181	062	172	158

TABLE 2.8. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 4; DYNAMIC INDEX 52

WING MODEL NACA 64A010. CHORD= 500 METERS

WING MOTION PITCHING 1 02 DEG ABOUT X/C = 248

DYNAMIC INDEX 52 STATIC INDEX 30

H	796	PTOT	203321	K	051
ALPHA	+ 21	QINF	59395	FREQ	8.6
RE	1 30E 07	PINF	133912		

-----UPPER SURFACE-----

STEADY DATA

UNSTEADY DATA

-----LOWER SURFACE-----

STEADY DATA

UNSTEADY DATA

----CPU----

X/C	CPU	X/C	REAL	IMAG	MAG	PHASE	X/C	CPU	X/C	REAL	IMAG	MAG	PHASE
030	- 086	033	- 9.518	3.334	10.086	160.71	053	- 207	034	10.999	- 3.944	11.685	- 19.73
091	+ 193	052	- 8.569	2.979	9.091	160.88	093	- 175	054	9.266	- 3.301	9.856	- 19.57
142	+ 292	091	- 7.723	2.634	8.160	161.18	142	- 316	094	7.994	- 2.835	8.481	- 19.53
211	- 378	140	- 6.621	2.449	7.247	160.26	199	- 320	141	7.267	- 2.615	7.723	- 19.79
243	- 418	209	- 6.132	2.094	6.400	161.16	244	- 457	200	6.540	- 2.340	6.946	- 19.69
292	- 481	243	- 6.282	2.192	6.654	160.78	293	- 500	243	5.766	- 1.987	6.099	- 19.01
341	- 544	294	- 6.270	2.245	6.660	160.31	341	- 536	293	4.808	- 1.754	5.117	- 20.04
399	- 635	402	- 7.275	2.494	7.690	161.09	393	- 629	341	5.825	- 2.031	6.169	- 19.22
440	- 703	440	- 7.936	2.648	8.366	161.56	440	- 713	394	5.638	- 1.968	5.972	- 19.24
487	- 594	488	- 13.828	3.754	14.326	164.82	490	- 777	490	13.385	- 3.652	13.874	- 15.26
537	- 322	538	- 2.389	- 208	2.398	- 175.03	537	- 334	582	675	591	897	41.19
585	- 258	584	- 860	- 1.073	1.376	- 51.30	583	- 255	631	- 272	746	794	110.07
634	- 181	633	- 153	- 1.717	1.733	- 77.97	625	- 198	678	- 368	681	771	118.35
682	- 132	733	- 111	- 1.473	486	- 103.25	679	- 137	733	- 225	514	561	113.70
733	- 061	781	- 009	- 1.398	398	- 91.26	734	- 070	781	- 168	390	424	113.31
827	041	829	033	- 1.376	377	- 84.95	789	- 008	631	- 275	363	455	127.18
874	092	872	083	- 1.284	296	- 73.78	832	- 043	868	- 206	244	319	130.22
924	141	941	031	- 1.117	121	- 75.09	906	- 113	923	- 147	130	196	138.40
							941	- 170					

----CPL----

X/C	CPL	X/C	REAL	IMAG	MAG	PHASE	X/C	CPL	X/C	REAL	IMAG	MAG	PHASE
030	- 207	034	10.999	- 3.944	11.685	- 19.73	093	- 175	054	9.266	- 3.301	9.856	- 19.57
091	- 175	094	7.994	- 2.835	8.481	- 19.53	142	- 316	141	7.267	- 2.615	7.723	- 19.79
142	- 316	141	7.267	- 2.615	7.723	- 19.79	199	- 320	141	7.267	- 2.615	7.723	- 19.79
211	- 320	200	6.540	- 2.340	6.946	- 19.69	244	- 457	200	6.540	- 2.340	6.946	- 19.69
243	- 500	243	5.766	- 1.987	6.099	- 19.01	293	- 629	341	5.825	- 2.031	6.169	- 19.22
341	- 536	341	5.825	- 2.031	6.169	- 19.22	393	- 629	341	5.825	- 2.031	6.169	- 19.22
399	- 629	402	4.808	- 1.754	5.117	- 20.04	440	- 713	394	5.638	- 1.968	5.972	- 19.24
440	- 713	440	4.808	- 1.754	5.117	- 20.04	487	- 594	488	13.385	- 3.652	13.874	- 15.26
487	- 594	488	13.385	- 3.652	13.874	- 15.26	537	- 334	582	675	591	897	41.19
537	- 334	582	675	591	897	41.19	585	- 255	631	- 272	746	794	110.07
585	- 255	631	- 272	746	794	110.07	634	- 198	678	- 368	681	771	118.35
634	- 198	678	- 368	681	771	118.35	682	- 137	733	- 225	514	561	113.70
682	- 137	733	- 225	514	561	113.70	733	- 070	781	- 168	390	424	113.31
733	- 070	781	- 168	390	424	113.31	827	- 043	868	- 206	244	319	130.22
827	- 043	868	- 206	244	319	130.22	874	- 092	906	- 113	923	- 147	138.40
874	- 092	906	- 113	923	- 147	138.40	924	- 141	941	- 031			
924	- 141	941	- 031					- 170					

TABLE 2.9. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 5; DYNAMIC INDEX 53

WING MODEL NACA 64A010. CHORD= 500 METERS

WING MOTION PITCHING 1 02 DEG ABOUT X/C = 248

DYNAMIC INDEX 53 STATIC INDEX 30

H	796	PTOT	203321	K	101
ALPHA	+ 21	QINF	59395	FREQ	17.2
RE	1 30E 07	PINF	133912		

-----UPPER SURFACE-----

STEADY DATA

UNSTEADY DATA

-----LOWER SURFACE-----

STEADY DATA

UNSTEADY DATA

----CPU----

X/C	CPU	X/C	REAL	IMAG	MAG	PHASE	X/C	CPU	X/C	REAL	IMAG	MAG	PHASE
030	- 086	033	- 7.014	4.042	8.023	145.39	053	- 207	034	8.191	- 8.798	10.035	- 26.29
091	+ 193	052	- 6.269	4.307	7.734	145.45	093	- 175	054	8.326	- 8.842	8.451	- 34.96
142	+ 292	091	- 5.761	2.894	8.972	146.02	142	- 316	094	8.642	- 1.122	7.232	- 34.75
211	- 378	140	- 6.065	3.541	6.180	145.04	199	- 320	141	7.136	- 2.754	6.974	- 34.84
243	- 418	209	- 6.029	3.136	5.591	145.29	244	- 457	200	6.347	- 2.054	8.200	- 23.29
292	- 481	243	- 6.724	2.792	5.792	145.23	293	- 500	243	6.573	- 1.123	8.540	- 24.32
341	- 544	294	- 6.850	3.201	9.702	144.64	341	- 536	293	6.649	- 2.604	4.483	- 26.52
399	- 635	402	- 5.478	3.653	6.584	148.31	393	- 629	341	6.466	- 2.942	5.348	- 23.38
440	- 703	440	- 6.159	3.073	7.295	147.04	440	- 713	364	4.232	- 7.731	9.037	- 32.84
487	- 594	488	- 12.060	5.962	13.453	153.71	490	- 277	490	11.946	- 4.497	12.764	- 20.63
537	- 322	538	- 1.901	- 0.620	2.505	- 161.47	537	- 134	582	681	- 1.336	1.614	- 70.98
585	- 266	584	- 364	- 1.000	1.050	- 17.70	583	- 295	631	- 1.153	1.404	1.413	- 96.33
634	- 161	633	- 105	- 1.176	1.181	- 95.13	629	- 198	678	- 204	1.201	1.218	- 99.68
682	- 132	733	- 235	- 1.763	2.799	- 107.13	619	- 137	733	- 150	915	927	- 99.29
733	- 061	781	- 0.97	- 1.64	0.71	- 98.34	734	- 070	781	- 117	725	744	- 98.08
827	041	829	- 0.63	- 1.610	0.62	- 98.06	789	- 006	831	- 201	658	704	- 110.92
874	092	872	- 0.00	- 1.459	0.49	- 98.00	832	- 043	868	- 174	473	564	- 110.24
924	141	941	0.09	- 1.79	1.76	- 98.02	866	- 113	923	- 167	274	311	- 116.17
							941	- 170					

TABLE 2.10. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 6; DYNAMIC INDEX 55

WING MODEL: NACA 64A010, CHORD= 500 METERS

WING MOTION: PITCHING 1.01 DEG ABOUT X/C = 248

DYNAMIC INDEX 55 STATIC INDEX 30

M	796	PTOT	203321	K	202
ALPHA	- 21	QINF	59395	FREQ	34.4
RE	1.30E 07	PINF	133912		

.....UPPER SURFACE.....

STEADY DATA

UNSTEADY DATA

STEADY DATA

UNSTEADY DATA

....CPU.....

....CPU A.....

....CPL.....

....CPL A.....

X/C	CPU	X/C	REAL	IMAG	HAG	PHASE	X/C	CPL	X/C	REAL	IMAG	HAG	PHASE
030	- .086	.033	-4.346	4.572	6.308	133.55	.053	- .207	.034	4.663	-5.537	7.239	-49.90
.091	- .193	.052	-3.397	4.217	5.810	133.46	.093	- .175	.054	3.979	-4.675	6.139	-49.60
.142	- .292	.091	-3.469	3.557	4.969	134.29	.142	- .316	.094	3.497	-4.034	5.339	-49.99
.211	- .378	.140	-3.036	3.205	4.415	133.46	.199	- .320	.141	3.236	-3.767	4.966	-49.34
.243	- .418	.209	-2.880	2.974	4.140	134.09	.244	- .457	.200	2.656	-2.792	3.861	-46.32
.292	- .481	.243	-3.023	3.176	4.385	133.60	.293	- .500	.243	3.075	-3.495	4.648	-48.5
.341	- .544	.294	-3.002	3.079	4.300	134.26	.341	- .536	.293	2.362	-2.726	3.607	-49.10
.399	- .635	.402	-4.081	3.723	5.524	137.64	.393	- .629	.341	3.173	-3.084	4.424	-44.19
.440	- .703	.440	-4.988	4.016	6.423	140.96	.440	- .713	.394	3.210	-2.902	4.381	-42.89
.487	- .594	.486	-11.922	4.745	12.832	158.31	.490	- .777	.490	11.825	-3.337	12.287	-15.76
.537	- .322	.538	-1.672	-2.139	2.714	-128.03	.537	- .333	.532	.616	-2.691	2.761	77.12
.585	- .258	.584	.128	-2.800	2.803	-87.39	.583	- .255	.631	.007	-2.480	2.480	89.85
.634	- .181	.633	-1.120	-2.064	2.068	-93.32	.625	- .198	.678	- .168	-2.091	2.097	94.60
.692	- .132	.733	-1.052	-1.338	1.339	-92.22	.679	- .137	.731	- .208	1.491	1.505	97.95
.733	- .061	.781	.066	-1.202	1.204	-86.85	.734	- .070	.781	- .171	1.316	1.327	97.42
.827	.041	.829	.161	-1.085	1.097	-81.55	.789	- .008	.831	- .398	1.119	1.187	109.48
.874	.092	.872	.156	-1.714	.731	-77.89	.832	- .049	.866	- .246	.708	.749	109.16
.924	.141	.941	.087	-1.264	.281	-69.84	.886	- .113	.923	- .170	.463	.494	110.21
							.941	- .170					

TABLE 2.11. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 7; DYNAMIC INDEX 57

WING MODEL: NACA 64A010, CHORD= 500 METERS

WING MOTION: PITCHING 1.01 DEG ABOUT X/C = 292

DYNAMIC INDEX 57 STATIC INDEX 30

M	796	PTOT	203321	K	203
ALPHA	- 21	QINF	59395	FREQ	31.9
RE	1.30E 07	PINF	133912		

.....UPPER SURFACE.....

STEADY DATA

UNSTEADY DATA

STEADY DATA

UNSTEADY DATA

....CPU.....

....CPU A.....

....CPL.....

....CPL A.....

X/C	CPU	X/C	REAL	IMAG	HAG	PHASE	X/C	CPL	X/C	REAL	IMAG	HAG	PHASE
030	- .053	.033	-4.971	3.043	5.081	147.20	.053	- .201	.034	1.116	-4.311	4.312	-168.47
.091	- .153	.052	-4.021	3.494	5.346	137.29	.093	- .175	.054	3.831	-3.391	5.479	-45.37
.142	- .292	.081	-3.241	3.997	4.888	148.12	.142	- .316	.094	2.813	-3.369	4.286	-160.13
.211	- .378	.143	-3.372	2.050	4.240	143.20	.199	- .320	.141	2.047	-3.419	4.507	-160.93
.243	- .418	.209	-2.110	2.976	4.303	156.39	.244	- .457	.200	2.374	-2.499	3.641	-166.27
.292	- .481	.243	-3.626	3.213	4.912	157.59	.293	- .500	.243	2.604	-3.162	4.650	-161.76
.341	- .544	.402	-7.313	4.219	8.357	149.68	.341	- .536	.293	2.164	-2.725	3.397	-161.16
.399	- .635	.443	-7.972	3.340	8.643	157.20	.399	- .579	.311	2.660	-2.201	4.224	-162.97
.440	- .703	.486	-13.300	-2.398	12.304	-170.77	.440	- .713	.394	2.449	-3.341	4.224	-162.71
.487	- .594	.536	-11.358	-1.719	4.911	-108.16	.490	- .771	.410	11.899	-16.060	13.662	-166.80
.537	- .322	.584	.526	-10.838	4.867	-103.76	.537	- .334	.582	3.266	-5.074	6.046	-167.06
.585	- .258	.633	-2.764	-2.778	5.052	-131.87	.583	- .356	.631	- .231	4.502	-4.508	97.94
.634	- .181	.723	.766	-2.966	3.043	-75.52	.629	- .169	.678	- .092	2.367	-2.900	104.79
.682	- .132	.701	.726	-2.369	2.504	-172.92	.679	- .137	.733	- .152	2.502	-2.391	120.52
.733	- .061	.829	.871	-1.459	2.462	-160.40	.734	- .059	.781	- .160	2.254	-2.333	109.00
.827	.041	.872	.792	-1.263	1.602	-160.36	.799	- .008	.831	- .145	1.882	-2.379	129.32
.874	.092	.841	.690	-1.521	.731	-168.29	.832	- .043	.866	- .176	1.108	-1.475	131.63
.924	.141						.866	- .113	.923	- .166	.623	.681	127.21
							.941	- .170					

TABLE 2.12. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 8; DYNAMIC INDEX 49

WING MODEL: NACA 64A010, CHORD= 500 METERS

WING MOTION: PITCHING 51 DEG ABOUT X/C: 247

DYNAMIC INDEX 49 STATIC INDEX 30

H	796	PTOT	203321	K	101
ALPHA	- 21	QINF	59395	FREQ	17.1
RE	1.30E 07	PINF	133912		

.....UPPER SURFACE.....

STEADY DATA UNSTEADY DATA

CPU		CPU, A				
X/C	CPU	X/C	REAL	IMAG	MAG	PHASE
030	- .096	.033	- 5.969	4.221	7.311	144.75
091	- .193	.052	- 6.089	4.153	7.371	145.71
142	- .292	.091	- 5.759	3.944	6.980	145.60
.211	- .378	.140	- 4.902	3.538	5.045	144.19
.243	- .418	.209	- 4.689	3.255	5.708	145.24
.292	- .481	.243	- 4.851	3.434	5.943	144.71
.341	- .544	.294	- 4.535	3.142	5.517	145.30
.399	- .635	.402	- 5.050	3.330	6.049	146.61
.440	- .703	.440	- 4.941	3.414	6.006	145.37
.487	- .594	.488	- 18.650	10.071	21.195	151.64
.537	- .322	.538	- .803	- 1.572	1.765	- 117.06
.585	- .268	.584	- .593	- 1.987	2.073	- 73.39
.634	- .181	.633	- .058	- 1.149	1.151	- 92.89
.682	- .132	.733	- .222	- 752	.784	- 106.45
.733	- .061	.781	- .114	- 642	.652	- 100.07
.827	.041	.829	- .030	- .593	.599	- 98.67
.874	.092	.872	- .018	- .431	.432	- 92.40
.924	.141	.941	- .018	- .175	.176	- 95.86

.....LOWER SURFACE.....

STEADY DATA UNSTEADY DATA

CPL		CPL, A				
X/C	CPL	X/C	REAL	IMAG	MAG	PHASE
052	- .207	.034	8.689	- 5.674	10.377	- 33.15
093	- .175	.054	6.979	- 4.989	8.578	- 35.56
142	- .316	.094	6.041	- 4.167	7.339	- 34.60
.199	- .320	.141	5.340	- 3.828	6.571	- 35.64
.244	- .47	.200	4.130	- 2.819	5.000	- 34.32
.293	- .500	.243	5.142	- 3.708	6.340	- 35.80
.341	- .536	.293	3.526	- 2.578	4.368	- 36.18
.393	- .629	.341	4.290	- 2.832	5.141	- 33.43
.440	- .713	.394	4.538	- 2.983	5.431	- 33.32
.490	- .777	.490	10.913	- 4.639	11.858	- 23.03
.537	- .334	.692	- 115	1.710	1.714	93.84
.583	- .255	.631	- 402	1.502	1.555	105.00
.625	- .198	.678	- 284	1.190	1.224	103.42
.679	- .137	.733	- 194	.943	.962	101.61
.734	- .070	.781	- .091	.718	.724	97.25
.789	- .006	.831	- 267	.660	.712	112.08
.832	.043	.886	- 164	.458	.486	109.70
.886	.113	.923	- 148	.270	.308	118.78
.941	.170					

TABLE 2.13. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 9; DYNAMIC INDEX 65

WING MODEL: NACA 64A010, CHORD= 500 METERS

WING MOTION: PITCHING 2.00 DEG ABOUT X/C: 239

DYNAMIC INDEX 65 STATIC INDEX 31

H	797	PTOT	203186	K	101
ALPHA	- .09	QINF	59423	FREQ	17.2
RE	1.24E 07	PINF	133724		

.....UPPER SURFACE.....

STEADY DATA UNSTEADY DATA

CPU		CPU, A				
X/C	CPU	X/C	REAL	IMAG	MAG	PHASE
030	- .099	.033	- 6.824	4.016	8.239	145.93
091	- .200	.052	- 6.621	4.830	8.026	145.84
142	- .299	.091	- 5.300	3.907	6.355	146.92
.211	- .385	.140	- 4.806	3.234	5.793	146.07
.243	- .426	.209	- 4.857	3.064	5.491	146.10
.292	- .488	.243	- 4.448	3.039	5.307	145.67
.341	- .551	.294	- 3.123	2.918	4.274	138.96
.399	- .643	.402	- 4.844	3.104	5.797	146.69
.440	- .716	.440	- 5.187	3.031	5.990	149.62
.487	- .729	.488	- 6.226	4.227	9.248	152.01
.537	- .323	.538	- 7.658	3.392	8.375	158.12
.585	- .254	.584	- 1.227	.746	1.436	- 148.73
.634	- .180	.633	- .067	- .862	.864	- 135.74
.682	- .130	.733	- .160	- .930	.943	- 99.78
.733	- .060	.781	.002	- .851	.851	- 89.85
.827	.042	.829	.112	- .740	.748	- 81.43
.874	.092	.872	.103	- .531	.541	- 79.00
.924	.140	.941	.009	- .224	.239	- 69.32

.....LOWER SURFACE.....

STEADY DATA UNSTEADY DATA

CPL		CPL, A				
X/C	CPL	X/C	REAL	IMAG	MAG	PHASE
090	- .021	.034	8.553	- 6.203	8.347	- 36.46
053	- .167	.054	6.730	- 4.885	8.150	- 34.23
142	- .309	.094	5.618	- 3.745	6.762	- 32.69
.244	- .450	.141	5.340	- 3.573	6.429	- 32.79
.293	- .497	.200	4.880	- 3.279	6.879	- 33.50
.341	- .613	.243	4.525	- 2.901	6.384	- 32.61
.393	- .627	.293	3.468	- 2.211	4.111	- 32.58
.440	- .713	.341	2.981	- 1.824	3.495	- 31.47
.490	- .764	.394	4.334	- 2.467	4.997	- 29.85
.537	- .350	.490	8.020	- 2.482	8.404	- 17.19
.583	- .354	.682	2.164	- 2.225	2.196	5.69
.625	- .197	.631	2.111	- 0.834	1.000	49.63
.679	- .137	.679	.260	- 0.957	.301	74.81
.734	- .071	.733	.003	- .825	.620	90.19
.789	- .008	.781	.009	- .713	.713	99.30
.832	.042	.886	.133	- .446	.466	106.65
.886	.111	.923	.190	- .277	.319	118.58
.941	.167					

TABLE 2.14. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE DATA
FOR AGARD CT CASE NO. 10; DYNAMIC INDEX 12

WING MODEL NACA 64A010. CHORD= 500 METERS

WING MOTION- PITCHING 94 DEG ABOUT X/C+ 232

DYNAMIC INDEX 12 STATIC INDEX 13

M	802	PTOT	50763	K	200
ALPHA	- .00	QINF	14953	FREQ	33.2
RE	3 40E 06	PINF	33251		

UPPER SURFACE										LOWER SURFACE									
STEADY DATA					UNSTEADY DATA					STEADY DATA					UNSTEADY DATA				
----CPU----		----CPU, A----			----CPL----		----CPL, A----			----CPU----		----CPU, A----			----CPL----		----CPL, A----		
X/C	CPU	X/C	REAL	IMAG	X/C	REAL	X/C	REAL	IMAG	X/C	CPL	X/C	REAL	IMAG	X/C	CPL	X/C	REAL	IMAG
030	-121	033	-3 850	4 490	5 915	130 62	053	-186	000	345	-322	472	-43 03	034	4 863	-4 966	6 950	-45 61	
052	-169	052	-4 211	3 919	5 752	137 06	093	-223	034	4 863	-4 966	6 950	-45 61	054	4 415	-4 477	6 298	-45 40	
091	-242	091	-3 825	3 394	5 114	138 42	142	-315	094	3 797	-3 665	5 277	-43 99	140	-3 325	2 834	4 369	139 58	
142	-339	140	-3 850	2 804	4 099	136 96	244	-448	141	3 528	-3 349	4 855	-43 52	142	-3 325	2 834	4 369	139 58	
211	-420	259	-2 990	2 804	4 099	136 96	293	-503	200	3 291	-2 883	4 375	-41 23	243	-465	243	-3 110	3 128	
243	-465	243	-3 110	3 128	4 411	134 85	341	-551	243	3 365	-2 925	4 459	-41 00	292	-522	339	-3 189	2 987	
341	-576	402	-4 394	3 759	5 782	139 46	393	-627	293	3 196	-2 883	4 304	-42 06	440	-693	440	-5 819	3 668	
497	-659	489	-6 677	4 318	7 952	147 12	440	-672	341	3 578	-3 096	4 731	-40 87	537	-11 290	539	-11 841	162 47	
537	-396	539	-11 290	3 568	11 841	162 47	537	-399	441	6 015	-2 916	6 684	-25 86	585	-224	584	-470	-2 720	
634	-160	633	055	-2 592	2 593	-88 80	625	-173	537	12 947	2 056	13 109	9 02	682	-115	682	309	-2 120	
733	-053	733	256	-1 560	1 580	-80 67	734	-061	631	-459	2 321	2 366	101 20	783	-001	781	086	-1 494	
827	039	829	092	-1 181	1 184	-86 05	832	043	733	-433	1 191	1 268	110 00	874	088	872	088	-1 029	
924	135	941	009	-643	543	-89 05	941	160	831	-862	712	1 118	140 46	923	-219	923	-219	484	
									888	-369	069	398	169 89					531	
									923	-219	484	531	114 40						

TABLE 2.15. INSTANTANEOUS LIFT AND MOMENT DATA; CT CASE NO. 6, DYNAMIC INDEX 55

TAU	WT/REF	ALPHA	CL	CD	CL	CD	CL	CD	CL	CD	CL	CD	CL	CD	CL	CD	CL	CD	CL	CD
1	-0.5	0.00	1.12	-0.0456	1.520	-0.007	0.022	-0.014	0.004	-0.0052	-0.004	-0.004	0.004	-0.004	0.004	-0.004	0.004	-0.004	0.004	-0.004
2	-0.5	0.50	1.02	-0.0400	1.531	-0.015	0.049	-0.010	0.010	-0.0063	-0.003	-0.003	0.003	-0.003	0.003	-0.003	0.003	-0.003	0.003	-0.003
3	-0.5	1.00	1.01	-0.031	1.531	-0.011	0.046	-0.008	0.011	-0.0053	-0.002	-0.002	0.002	-0.002	0.002	-0.002	0.002	-0.002	0.002	-0.002
4	-0.5	1.50	1.01	-0.026	1.530	-0.008	0.045	-0.007	0.012	-0.0053	-0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001	0.001	-0.001
5	-0.5	2.00	1.01	-0.024	1.529	-0.006	0.044	-0.006	0.013	-0.0052	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
6	-0.5	2.50	1.01	-0.023	1.528	-0.004	0.043	-0.005	0.014	-0.0051	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
7	-0.5	3.00	1.01	-0.022	1.527	-0.003	0.042	-0.004	0.015	-0.0050	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
8	-0.5	3.50	1.01	-0.021	1.526	-0.002	0.041	-0.003	0.016	-0.0049	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
9	-0.5	4.00	1.01	-0.020	1.525	-0.001	0.040	-0.002	0.017	-0.0048	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
10	-0.5	4.50	1.01	-0.019	1.524	-0.001	0.039	-0.001	0.018	-0.0047	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
11	-0.5	5.00	1.01	-0.018	1.523	-0.001	0.038	-0.001	0.019	-0.0046	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
12	-0.5	5.50	1.01	-0.017	1.522	-0.001	0.037	-0.001	0.020	-0.0045	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
13	-0.5	6.00	1.01	-0.016	1.521	-0.001	0.036	-0.001	0.021	-0.0044	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
14	-0.5	6.50	1.01	-0.015	1.520	-0.001	0.035	-0.001	0.022	-0.0043	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
15	-0.5	7.00	1.01	-0.014	1.519	-0.001	0.034	-0.001	0.023	-0.0042	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
16	-0.5	7.50	1.01	-0.013	1.518	-0.001	0.033	-0.001	0.024	-0.0041	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
17	-0.5	8.00	1.01	-0.012	1.517	-0.001	0.032	-0.001	0.025	-0.0040	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
18	-0.5	8.50	1.01	-0.011	1.516	-0.001	0.031	-0.001	0.026	-0.0039	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
19	-0.5	9.00	1.01	-0.010	1.515	-0.001	0.030	-0.001	0.027	-0.0038	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
20	-0.5	9.50	1.01	-0.009	1.514	-0.001	0.029	-0.001	0.028	-0.0037	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
21	-0.5	10.00	1.01	-0.008	1.513	-0.001	0.028	-0.001	0.029	-0.0036	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
22	-0.5	10.50	1.01	-0.007	1.512	-0.001	0.027	-0.001	0.030	-0.0035	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
23	-0.5	11.00	1.01	-0.006	1.511	-0.001	0.026	-0.001	0.031	-0.0034	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
24	-0.5	11.50	1.01	-0.005	1.510	-0.001	0.025	-0.001	0.032	-0.0033	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
25	-0.5	12.00	1.01	-0.004	1.509	-0.001	0.024	-0.001	0.033	-0.0032	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
26	-0.5	12.50	1.01	-0.003	1.508	-0.001	0.023	-0.001	0.034	-0.0031	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
27	-0.5	13.00	1.01	-0.002	1.507	-0.001	0.022	-0.001	0.035	-0.0030	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
28	-0.5	13.50	1.01	-0.001	1.506	-0.001	0.021	-0.001	0.036	-0.0029	-0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000
29	-0.5	14.00	1.01	0.000	1.505	-0.001	0.020	-0.001	0.037	-0.0028	-0.000	-0.000								

TABLE 2.16. INSTANTANEOUS PRESSURES AT UPPER-SURFACE; CT CASE NO. 6, DYNAMIC INDEX 55

	J=	1	2	3	4	5	6	7	8	9	10	11	12	13
PHASE,DEG#	-5.5	.5	6.5	12.5	18.5	24.5	30.5	36.5	42.5	48.5	54.5	60.5	66.5	
ALPHA,DEG#	1.019	1.021	1.012	.991	.958	.915	.862	.800	.730	.653	.570	.491	.387	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.033	-.161	-.167	-.173	-.182	-.191	-.198	-.202	-.203	-.202	-.201	-.200	-.198	-.195
2	.052	-.187	-.196	-.204	-.210	-.214	-.218	-.222	-.225	-.225	-.224	-.222	-.219	-.217
3	.091	-.258	-.259	-.265	-.269	-.272	-.275	-.277	-.277	-.278	-.277	-.275	-.271	-.264
4	.140	-.339	-.346	-.350	-.355	-.358	-.360	-.362	-.364	-.364	-.363	-.361	-.356	-.356
5	.209	-.422	-.429	-.433	-.438	-.445	-.442	-.445	-.445	-.445	-.442	-.440	-.439	-.437
6	.243	-.460	-.474	-.480	-.484	-.486	-.486	-.490	-.490	-.490	-.488	-.487	-.486	-.484
7	.294	-.530	-.535	-.541	-.546	-.549	-.551	-.554	-.555	-.555	-.553	-.552	-.550	-.549
8	.402	-.709	-.715	-.720	-.721	-.723	-.726	-.727	-.724	-.723	-.722	-.724	-.723	-.716
9	.440	-.777	-.782	-.785	-.788	-.790	-.791	-.791	-.790	-.790	-.789	-.790	-.789	-.786
10	.488	-.777	-.786	-.792	-.795	-.796	-.795	-.794	-.792	-.792	-.795	-.795	-.789	-.784
11	.536	-.349	-.350	-.352	-.346	-.342	-.340	-.337	-.334	-.328	-.322	-.313	-.304	-.299
12	.584	-.262	-.259	-.247	-.240	-.238	-.233	-.229	-.225	-.219	-.215	-.213	-.213	-.217
13	.633	-.187	-.181	-.176	-.172	-.168	-.165	-.160	-.157	-.154	-.153	-.150	-.153	-.155
14	.733	-.059	-.056	-.055	-.055	-.050	-.048	-.045	-.042	-.039	-.039	-.040	-.043	-.042
15	.781	-.008	-.004	-.002	-.000	.003	.006	.008	.007	.009	.009	.008	.007	.009
16	.829	.043	.047	.049	.055	.060	.064	.065	.067	.066	.064	.061	.060	
17	.872	.092	.094	.096	.098	.100	.101	.101	.102	.102	.103	.102	.102	
18	.941	.160	.159	.160	.161	.160	.160	.160	.160	.160	.160	.161	.162	
	J=	14	15	16	17	18	19	20	21	22	23	24	25	26
PHASE,DEG#	72.5	76.5	84.5	90.5	96.5	102.5	108.5	114.5	120.5	126.5	132.5	138.5	144.5	
ALPHA,DEG#	.290	.190	.088	-.014	-.116	-.216	-.313	-.407	-.497	-.583	-.664	-.736	-.806	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.033	-.190	-.185	-.179	-.171	-.164	-.157	-.146	-.137	-.126	-.115	-.099	-.087	-.072
2	.052	-.213	-.208	-.202	-.196	-.188	-.181	-.173	-.165	-.153	-.142	-.132	-.122	
3	.091	-.264	-.260	-.255	-.250	-.240	-.237	-.229	-.218	-.209	-.200	-.191	-.183	
4	.140	-.353	-.349	-.345	-.340	-.337	-.332	-.327	-.321	-.314	-.306	-.298	-.289	
5	.209	-.455	-.451	-.448	-.443	-.449	-.441	-.441	-.445	-.439	-.432	-.377	-.370	
6	.243	-.481	-.477	-.474	-.470	-.466	-.464	-.459	-.453	-.446	-.437	-.428	-.420	
7	.294	-.544	-.541	-.538	-.537	-.536	-.532	-.525	-.515	-.509	-.502	-.493	-.484	
8	.402	-.715	-.707	-.703	-.700	-.696	-.689	-.682	-.676	-.666	-.658	-.651	-.642	
9	.440	-.763	-.761	-.778	-.774	-.769	-.763	-.757	-.749	-.742	-.738	-.735	-.718	
10	.488	-.777	-.768	-.761	-.745	-.728	-.696	-.651	-.596	-.543	-.486	-.434	-.397	
11	.536	-.297	-.293	-.285	-.278	-.273	-.266	-.262	-.261	-.259	-.259	-.259	-.261	
12	.584	-.219	-.216	-.213	-.213	-.213	-.215	-.218	-.221	-.222	-.223	-.226	-.232	
13	.633	-.153	-.148	-.147	-.150	-.151	-.155	-.150	-.146	-.151	-.153	-.148	-.158	
14	.733	-.043	-.041	-.042	-.043	-.043	-.045	-.047	-.042	-.038	-.039	-.043	-.046	
15	.781	.009	.009	.009	.008	.007	.010	.010	.008	.005	.007	.007	.005	
16	.829	.057	.056	.055	.055	.056	.056	.056	.054	.052	.052	.052	.054	
17	.872	.101	.101	.101	.101	.101	.101	.100	.099	.098	.098	.098	.099	
18	.941	.162	.160	.163	.162	.160	.158	.157	.157	.156	.156	.156	.159	
	J=	27	28	29	30	31	32	33	34	35	36	37	38	39
PHASE,DEG#	150.5	156.5	162.5	168.5	174.5	180.5	186.5	192.5	198.5	204.5	210.5	216.5	222.5	
ALPHA,DEG#	-.866	-.918	-.960	-.991	-.994	-.998	-.999	-.998	-.996	-.995	-.994	-.993	-.994	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.033	-.057	-.063	-.064	-.065	-.068	-.072	-.074	-.078	-.081	-.082	-.084	-.081	-.078
2	.052	-.094	-.088	-.077	-.068	-.060	-.052	-.045	-.037	-.031	-.027	-.024	-.021	-.021
3	.091	-.177	-.184	-.188	-.184	-.181	-.174	-.162	-.151	-.143	-.139	-.134	-.130	-.125
4	.140	-.270	-.265	-.258	-.250	-.243	-.235	-.228	-.222	-.214	-.214	-.210	-.209	-.200
5	.209	-.394	-.386	-.380	-.374	-.368	-.362	-.357	-.351	-.343	-.339	-.330	-.329	-.320
6	.243	-.481	-.482	-.484	-.482	-.482	-.482	-.482	-.482	-.482	-.482	-.482	-.482	-.482
7	.294	-.525	-.515	-.504	-.494	-.484	-.474	-.464	-.454	-.444	-.434	-.424	-.414	-.403
8	.402	-.727	-.725	-.723	-.721	-.718	-.715	-.712	-.708	-.704	-.700	-.696	-.692	-.686
9	.440	-.786	-.784	-.782	-.780	-.778	-.776	-.774	-.772	-.770	-.768	-.766	-.764	-.762
10	.488	-.836	-.834	-.832	-.830	-.828	-.826	-.824	-.822	-.820	-.818	-.816	-.814	-.812
11	.536	-.267	-.273	-.277	-.281	-.285	-.289	-.293	-.297	-.301	-.305	-.309	-.313	-.319
12	.584	-.237	-.241	-.247	-.250	-.252	-.255	-.258	-.261	-.264	-.267	-.270	-.273	-.276
13	.633	-.165	-.167	-.172	-.175	-.179	-.182	-.185	-.188	-.191	-.194	-.196	-.198	-.201
14	.733	-.089	-.088	-.085	-.083	-.082	-.080	-.078	-.076	-.074	-.072	-.070	-.068	-.067
15	.781	.023	.022	.021	.020	.019	.018	.017	.016	.015	.014	.013	.012	.011
16	.829	.057	.056	.055	.055	.056	.056	.056	.056	.056	.056	.056	.056	.056
17	.872	.098	.094	.093	.092	.091	.090	.089	.088	.087	.086	.085	.084	.083
18	.941	.161	.159	.159	.159	.159	.159	.159	.159	.159	.159	.159	.159	.159
	J=	40	41	42	43	44	45	46	47	48	49	50	51	52
PHASE,DEG#	226.5	232.5	240.5	246.5	252.5	258.5	264.5	270.5	276.5	282.5	288.5	294.5	300.5	
ALPHA,DEG#	-.958	-.953	-.949	-.944	-.939	-.934	-.929	-.924	-.919	-.914	-.909	-.904	-.900	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.033	.018	.016	.015	.014	.013	.012	.011	.010	.009	.008	.007	.006	.005
2	.052	-.021	-.020	-.019	-.018	-.017	-.016	-.015	-.014	-.013	-.012	-.011	-.010	-.009
3	.091	-.103	-.104	-.105	-.106	-.107	-.108	-.109	-.110	-.111	-.112	-.113	-.114	-.115
4	.140	-.207	-.204	-.201	-.198	-.195	-.192	-.189	-.186	-.183	-.180	-.177	-.174	-.171
5	.209	-.392	-.388	-.384	-.380	-.376	-.372	-.368	-.364	-.360	-.356	-.352	-.348	-.344
6	.243	-.438	-.434	-.430	-.426	-.422	-.418	-.414	-.410	-.406	-.402	-.398	-.394	-.390
7	.294	-.510	-.506	-.502	-.498	-.494	-.490	-.486	-.482	-.478	-.474	-.470	-.466	-.462
8	.402	-.534	-.531	-.528	-.525	-.522	-.519	-.516	-.513	-.510	-.507	-.504	-.501	-.498
9	.440	-.534	-.529	-.523	-.517	-.511	-.505	-.500	-.495	-.490	-.485	-.480	-.475	-.470
10	.488	-.510	-.505	-.500	-.495	-.490	-.485	-.480	-.475	-.470	-.465	-.460	-.455	-.450
11	.536	-.280	-.276	-.272	-.268	-.264	-.260	-.256	-.252	-.248	-.244	-.240	-.236	-.232

TABLE 2.16 CONCLUDED.

	J*	53	54	55	56	57	58	59	60	61	62	63	64	65
PHASE,DEG	306.5	312.5	318.5	324.5	330.5	336.5	342.5	348.5	354.5	360.5	366.5	372.5	378.5	
ALPHA,DEG	.599	.681	.756	.823	.882	.931	.971	1.000	1.017	1.021	1.014	.994	.983	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	*
1	.033	-.062	-.074	-.089	-.104	-.116	-.129	-.142	-.152	-.160	-.167	-.173	-.181	-.190
2	.052	-.107	-.117	-.128	-.138	-.149	-.158	-.166	-.177	-.186	-.195	-.204	-.210	-.213
3	.091	-.161	-.189	-.200	-.210	-.219	-.228	-.236	-.245	-.253	-.259	-.265	-.269	-.271
4	.140	-.277	-.286	-.295	-.303	-.310	-.316	-.326	-.333	-.339	-.345	-.350	-.354	-.357
5	.209	-.367	-.376	-.384	-.391	-.398	-.405	-.411	-.417	-.422	-.428	-.432	-.435	-.439
6	.243	-.409	-.420	-.428	-.434	-.440	-.447	-.454	-.462	-.468	-.473	-.478	-.482	-.486
7	.294	-.478	-.485	-.493	-.499	-.506	-.513	-.519	-.524	-.530	-.533	-.538	-.544	-.548
8	.402	-.648	-.656	-.665	-.673	-.683	-.689	-.695	-.700	-.706	-.712	-.718	-.722	-.724
9	.440	-.727	-.735	-.743	-.750	-.758	-.762	-.765	-.771	-.775	-.779	-.785	-.791	-.795
10	.488	-.636	-.657	-.681	-.705	-.720	-.733	-.748	-.762	-.774	-.784	-.793	-.796	-.799
11	.538	-.354	-.352	-.352	-.353	-.352	-.351	-.352	-.351	-.348	-.347	-.346	-.345	-.342
12	.584	-.297	-.292	-.291	-.287	-.284	-.280	-.272	-.267	-.265	-.259	-.251	-.245	-.238
13	.633	-.215	-.214	-.210	-.206	-.204	-.201	-.198	-.191	-.187	-.183	-.178	-.173	-.165
14	.733	-.083	-.081	-.080	-.077	-.076	-.071	-.068	-.064	-.059	-.055	-.053	-.052	-.051
15	.781	-.025	-.023	-.021	-.022	-.020	-.016	-.015	-.012	-.008	-.004	-.003	-.000	-.004
16	.829	.029	.030	.031	.029	.031	.034	.036	.040	.044	.047	.049	.055	.059
17	.872	.082	.084	.084	.083	.086	.087	.088	.092	.095	.096	.095	.098	.099
18	.901	.155	.158	.158	.154	.153	.155	.150	.160	.161	.159	.160	.161	.160

TABLE 2.17. STEADY AND FUNDAMENTAL FREQUENCY PRESSURE DATA: SHOCK-STALL CASE

WING MODEL: NACA 64A010, CHORD: 500 METERS

WING MOTION PITCHING 1 G DEG ABOUT Y/C 249

DYNAMIC INDEX 89 STATIC INDEX 44

M 799 PTOT 203169 X 204
 ALPHA 4 GO QINF 58714 FREQ 351
 RE 1 20E 97 PINF 134741

.....UPPER SURFACE

.....LOWER SURFACE

STEADY DATA

UNSTEADY CAT

STEADY DATA

UNSTEADY DATA

TABLE 2.18. INSTANTANEOUS PRESSURES AT UPPER-SURFACE; SHOCK STALL CASE, DYNAMIC INDEX 89

	J#	1	2	3	4	5	6	7	8	9	10	11	12	13
PHASE,DEG=	-11.2	.52	.8	6.8	12.8	18.8	24.8	30.8	36.8	42.8	48.8	54.8	60.8	
ALPHA,DEG=	1.009	1.025	1.026	1.019	.998	.966	.925	.870	.809	.734	.662	.577	.487	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.052	-1.013	-1.022	-1.028	-1.033	-1.037	-1.040	-1.041	-1.041	-1.040	-1.039	-1.036	-1.035	-1.030
2	.091	-1.009	-1.017	-1.023	-1.027	-1.032	-1.036	-1.037	-1.038	-1.039	-1.037	-1.035	-1.032	-1.028
3	.140	-1.033	-1.042	-1.049	-1.054	-1.058	-1.061	-1.063	-1.064	-1.064	-1.063	-1.061	-1.059	-1.055
4	.209	-1.014	-1.021	-1.028	-1.034	-1.039	-1.043	-1.045	-1.047	-1.047	-1.047	-1.046	-1.045	-1.042
5	.283	-1.037	-1.045	-1.050	-1.056	-1.062	-1.066	-1.069	-1.071	-1.072	-1.072	-1.071	-1.071	-1.068
6	.394	-1.084	-1.092	-1.100	-1.109	-1.117	-1.121	-1.122	-1.126	-1.128	-1.126	-1.120	-1.118	-1.112
7	.539	-1.139	-1.147	-1.155	-1.162	-1.168	-1.172	-1.176	-1.179	-1.181	-1.182	-1.183	-1.182	-1.172
8	.602	-1.402	-1.412	-1.422	-1.429	-1.437	-1.444	-1.447	-1.424	-1.525	-1.119	-0.910	-0.803	-0.744
9	.440	-0.991	-0.997	-1.000	-1.005	-0.987	-0.888	-0.715	-0.580	-0.504	-0.462	-0.436	-0.420	-0.404
10	.488	-0.853	-0.728	-0.632	-0.564	-0.521	-0.485	-0.457	-0.431	-0.408	-0.392	-0.373	-0.355	-0.343
11	.538	-0.623	-0.610	-0.596	-0.581	-0.569	-0.557	-0.539	-0.527	-0.515	-0.497	-0.483	-0.471	-0.455
12	.584	-0.595	-0.591	-0.585	-0.578	-0.572	-0.564	-0.548	-0.536	-0.519	-0.504	-0.490	-0.475	-0.461
13	.633	-0.562	-0.566	-0.561	-0.565	-0.554	-0.543	-0.533	-0.524	-0.510	-0.495	-0.480	-0.466	-0.447
14	.733	-0.414	-0.429	-0.446	-0.455	-0.464	-0.471	-0.464	-0.454	-0.448	-0.437	-0.429	-0.417	-0.405
15	.781	-0.321	-0.340	-0.364	-0.366	-0.400	-0.413	-0.421	-0.412	-0.411	-0.405	-0.400	-0.397	-0.381
16	.829	-0.207	-0.235	-0.266	-0.300	-0.329	-0.345	-0.362	-0.365	-0.364	-0.370	-0.363	-0.361	-0.354
17	.872	-0.093	-0.126	-0.163	-0.188	-0.226	-0.257	-0.285	-0.295	-0.306	-0.318	-0.316	-0.314	
18	.941	.052	.024	-.001	-.038	-.077	-.119	-.153	-.180	-.200	-.215	-.226	-.224	-.231
	J#	14	15	16	17	18	19	20	21	22	23	24	25	26
PHASE,DEG=	66.8	72.8	78.8	84.8	90.8	96.8	102.8	108.8	114.8	120.8	126.8	132.8	138.8	
ALPHA,DEG=	.392	.294	.192	.088	-.016	-.120	-.223	-.324	-.421	-.514	-.602	-.682	-.759	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.052	-1.024	-1.019	-1.012	-1.006	-0.998	-0.991	-0.983	-0.974	-0.966	-0.958	-0.950	-0.941	-0.933
2	.091	-1.024	-1.019	-1.014	-1.008	-1.000	-0.993	-0.987	-0.979	-0.971	-0.964	-0.955	-0.946	-0.936
3	.140	-1.051	-1.047	-1.042	-1.037	-1.031	-1.024	-1.016	-1.006	-1.000	-0.991	-0.982	-0.973	-0.964
4	.209	-1.039	-1.035	-1.032	-1.027	-1.022	-1.016	-1.010	-1.004	-0.990	-0.981	-0.974	-0.966	-0.959
5	.293	-1.066	-1.063	-1.060	-1.056	-1.052	-1.047	-1.041	-1.036	-1.029	-1.024	-1.016	-1.012	-1.005
6	.394	-1.123	-1.121	-1.119	-1.116	-1.111	-1.106	-1.100	-1.098	-1.093	-1.089	-1.081	-1.077	-1.073
7	.539	-1.139	-1.099	-1.051	-1.010	-0.982	-0.964	-0.933	-0.906	-0.868	-0.877	-0.888	-0.905	-1.010
8	.602	-0.714	-0.694	-0.683	-0.674	-0.664	-0.657	-0.655	-0.653	-0.651	-0.655	-0.658	-0.661	
9	.440	-0.393	-0.381	-0.375	-0.371	-0.363	-0.359	-0.357	-0.355	-0.352	-0.348	-0.351	-0.350	-0.351
10	.488	-0.335	-0.326	-0.325	-0.314	-0.311	-0.299	-0.301	-0.295	-0.296	-0.290	-0.288	-0.290	
11	.538	-0.445	-0.433	-0.428	-0.424	-0.413	-0.412	-0.406	-0.402	-0.399	-0.389	-0.389	-0.386	-0.385
12	.584	-0.447	-0.430	-0.426	-0.421	-0.415	-0.404	-0.402	-0.399	-0.396	-0.387	-0.386	-0.382	-0.372
13	.633	-0.435	-0.425	-0.413	-0.408	-0.400	-0.391	-0.386	-0.381	-0.375	-0.366	-0.361	-0.351	-0.345
14	.733	-0.399	-0.382	-0.373	-0.365	-0.358	-0.351	-0.338	-0.332	-0.325	-0.318	-0.304	-0.298	-0.286
15	.781	-0.371	-0.356	-0.346	-0.338	-0.332	-0.323	-0.303	-0.304	-0.290	-0.288	-0.274	-0.264	-0.251
16	.829	-0.344	-0.334	-0.319	-0.311	-0.301	-0.300	-0.292	-0.274	-0.259	-0.255	-0.244	-0.235	-0.225
17	.872	-0.308	-0.298	-0.287	-0.279	-0.265	-0.265	-0.260	-0.244	-0.219	-0.214	-0.210	-0.204	-0.197
18	.941	-0.231	-0.229	-0.219	-0.210	-0.199	-0.191	-.104	-.176	-.149	-.144	-.143	-.130	-.113
	J#	27	26	24	20	18	16	14	12	10	8	6	4	2
PHASE,DEG=	144.8	150.8	156.8	162.8	168.8	174.8	180.8	186.8	192.8	198.8	204.8	210.8	216.8	
ALPHA,DEG=	.8827	.8866	.8936	.979	-1.003	-1.019	-1.022	-1.013	-0.993	-0.981	-0.978	-0.965	-0.904	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.052	-0.983	-0.918	-0.905	-0.857	-0.890	-0.895	-0.880	-0.873	-0.871	-0.868	-0.865	-0.863	-0.866
2	.091	-0.925	-0.914	-0.907	-0.890	-0.891	-0.885	-0.880	-0.870	-0.866	-0.863	-0.861	-0.862	
3	.140	-0.949	-0.945	-0.938	-0.920	-0.919	-0.911	-0.908	-0.904	-0.902	-0.900	-0.899	-0.898	-0.897
4	.209	-0.981	-0.954	-0.948	-0.941	-0.935	-0.924	-0.914	-0.904	-0.894	-0.884	-0.874	-0.864	-0.854
5	.293	-0.948	-0.941	-0.935	-0.924	-0.917	-0.907	-0.895	-0.885	-0.875	-0.865	-0.855	-0.845	-0.834
6	.394	-1.040	-1.049	-1.044	-1.039	-1.033	-1.026	-1.019	-1.012	-1.004	-0.996	-0.986	-0.976	-0.966
7	.539	-1.081	-1.083	-1.081	-1.078	-1.075	-1.072	-1.069	-1.066	-1.063	-1.060	-1.057	-1.054	-1.050
8	.602	-0.988	-0.981	-0.979	-0.977	-0.974	-0.972	-0.969	-0.966	-0.963	-0.960	-0.957	-0.954	-0.950
9	.440	-0.888	-0.884	-0.880	-0.879	-0.878	-0.877	-0.876	-0.875	-0.874	-0.873	-0.872	-0.871	-0.870
10	.488	-0.881	-0.876	-0.873	-0.870	-0.868	-0.867	-0.866	-0.865	-0.864	-0.863	-0.862	-0.861	-0.860
11	.538	-0.973	-0.971	-0.967	-0.964	-0.962	-0.960	-0.958	-0.956	-0.954	-0.952	-0.950	-0.948	-0.946
12	.584	-0.939	-0.934	-0.930	-0.926	-0.922	-0.918	-0.914	-0.910	-0.906	-0.902	-0.900	-0.898	-0.896
13	.633	-0.930	-0.931	-0.932	-0.934	-0.935	-0.936	-0.937	-0.938	-0.939	-0.940	-0.941	-0.942	-0.943
14	.733	-0.973	-0.971	-0.969	-0.967	-0.965	-0.963	-0.961	-0.959	-0.957	-0.955	-0.953	-0.951	-0.949
15	.781	-0.936	-0.928	-0.920	-0.912	-0.904	-0.896	-0.888	-0.880	-0.872	-0.864	-0.856	-0.848	-0.839
16	.829	-0.900	-0.893	-0.886	-0.879	-0.872	-0.865	-0.858	-0.850	-0.842	-0.834	-0.826	-0.818	-0.807
17	.872	-0.849	-0.848	-0.845	-0.842	-0.839	-0.836	-0.833	-0.830	-0.827	-0.824	-0.821	-0.818	-0.815
18	.941	-0.818	-0.808	-0.803	-0.802	-0.802	-0.802	-0.802	-0.802	-0.802	-0.802	-0.802	-0.802	-0.802
	J#	60	57	54	52	50	48	45	42	40	38	35	32	28
PHASE,DEG=	202.8	204.8	210.8	216.8	221.8	226.8	232.8	238.8	244.8	250.8	256.8	262.8	268.8	
ALPHA,DEG=	-0.735	-0.658	-0.575	-0.486	-0.393	-0.295	-0.194	-0.091	-0.001	-0.883	-0.883	-0.883	-0.883	
I	X/C	*	*	*	*	*	*	*	*	*	*	*	*	
1	.052	-0.888	-0.884	-0.870	-0.872	-0.877	-0.881	-0.886	-0.891	-0.896	-0.899	-0.903	-0.906	-0.902
2	.091	-0.881	-0.866	-0.863	-0.860	-0.862	-0.866	-0.869	-0.872	-0.875	-0.878	-0.881	-0.884	-0.887
3	.140	-0.882	-0.878	-0.875	-0.870	-0.876	-0.878	-0.880	-0.882	-0.884	-0.886	-0.888	-0.890	-0.892
4	.209	-0.900	-0.894	-0.886	-0.878	-0.875	-0.870	-0.86						

TABLE 2.18 CONCLUDED.

	52	53	54	55	56	57	58	59	60	61	62	63	64	65	
PHASE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
1	.000	-.929	-.938	-.947	-.958	-.970	-.981	-.992	-1.002	-1.012	-1.021	-1.028	-1.033	-1.037	
2	.091	-.927	-.936	-.945	-.956	-.967	-.980	-.990	-.998	-1.007	-1.015	-1.021	-1.027	-1.032	
3	.140	-.937	-.946	-.955	-.964	-.973	-.986	-.998	-1.010	-1.021	-1.031	-1.040	-1.047	-1.056	
4	.204	-.932	-.940	-.949	-.958	-.961	-.972	-.983	-.993	-1.003	-1.012	-1.021	-1.027	-1.034	-1.059
5	.245	-.939	-.948	-.957	-.967	-.977	-.987	-.998	-1.008	-1.017	-1.027	-1.035	-1.043	-1.049	-1.056
6	.294	-.994	-1.009	-1.019	-1.029	-1.041	-1.052	-1.062	-1.072	-1.082	-1.091	-1.100	-1.107	-1.115	
7	.354	-1.050	-1.061	-1.071	-1.084	-1.090	-1.100	-1.111	-1.124	-1.139	-1.147	-1.154	-1.161	-1.167	
8	.402	-1.051	-1.056	-1.059	-1.067	-1.077	-1.087	-1.097	-1.106	-1.114	-1.121	-1.128	-1.135	-1.142	-1.149
9	.440	-0.755	-0.739	-0.740	-0.734	-0.727	-0.719	-0.711	-0.704	-0.696	-0.686	-0.676	-0.666	-0.656	-0.646
10	.488	-0.994	-1.005	-1.012	-1.021	-1.025	-1.031	-1.031	-1.036	-1.046	-1.056	-1.065	-1.075	-1.085	-1.097
11	.530	-0.642	-0.653	-0.659	-0.659	-0.654	-0.644	-0.635	-0.629	-0.619	-0.608	-0.594	-0.579	-0.569	-0.559
12	.584	-0.563	-0.576	-0.586	-0.590	-0.594	-0.596	-0.592	-0.594	-0.593	-0.587	-0.580	-0.576	-0.568	-0.560
13	.633	-0.471	-0.493	-0.513	-0.528	-0.538	-0.549	-0.552	-0.560	-0.562	-0.562	-0.562	-0.560	-0.556	-0.552
14	.733	-0.205	-0.230	-0.261	-0.291	-0.318	-0.353	-0.378	-0.405	-0.416	-0.454	-0.443	-0.455	-0.462	-0.468
15	.781	-0.087	-0.102	-0.122	-0.149	-0.190	-0.218	-0.265	-0.300	-0.320	-0.345	-0.369	-0.377	-0.398	-0.417
16	.829	.011	.005	.007	.021	.044	.060	.118	.182	.210	.239	.270	.296	.323	.350
17	.872	.057	.057	.054	.048	.038	.021	.012	.050	.084	.124	.159	.197	.224	.252
18	.941	.126	.127	.128	.127	.124	.113	.101	.083	.057	.028	.003	.038	.075	.113

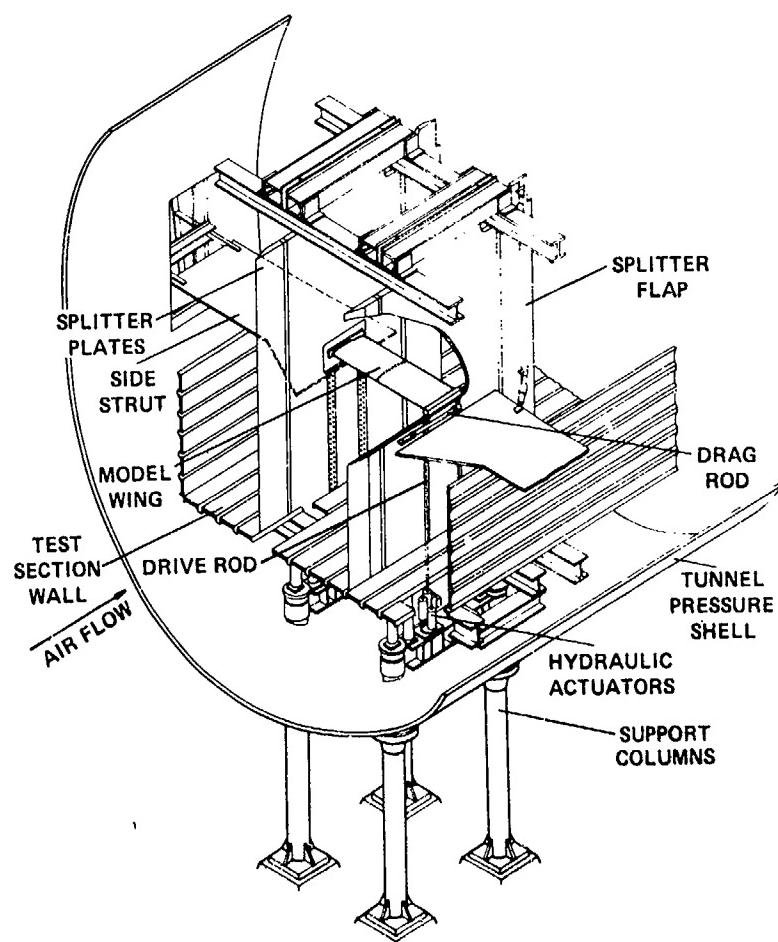


Fig. 2.1. General arrangement of oscillating airfoil test apparatus in NASA Ames 11- by 11-Foot Transonic Wind Tunnel.

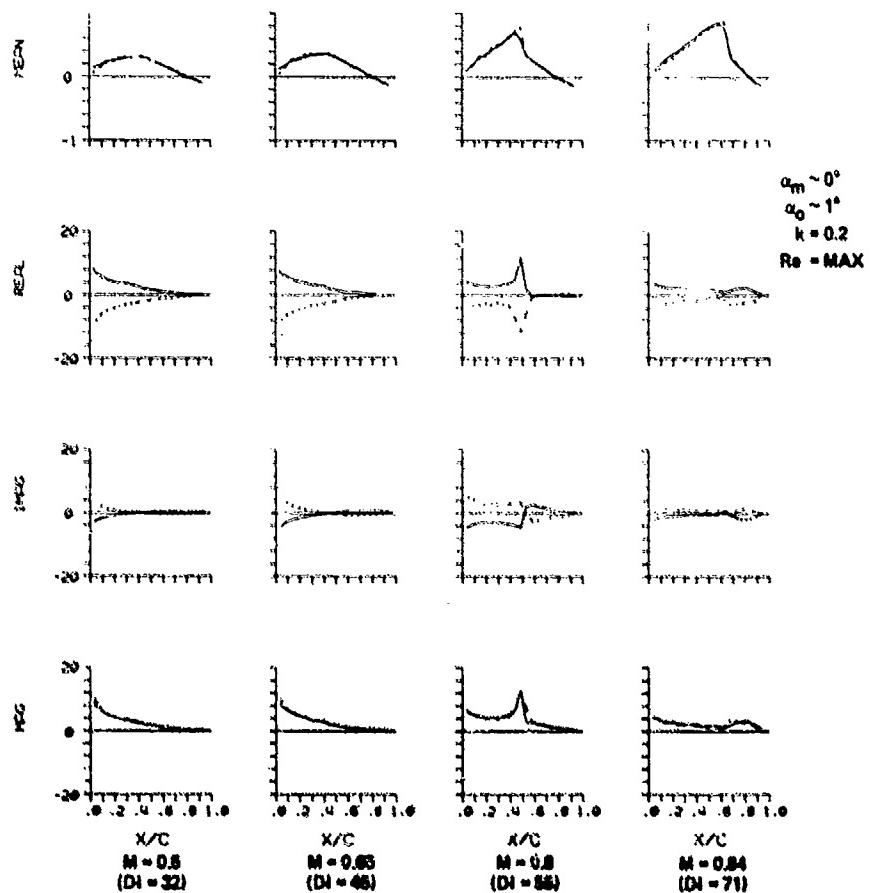


Fig. 2.2. Effect of varying Mach number.

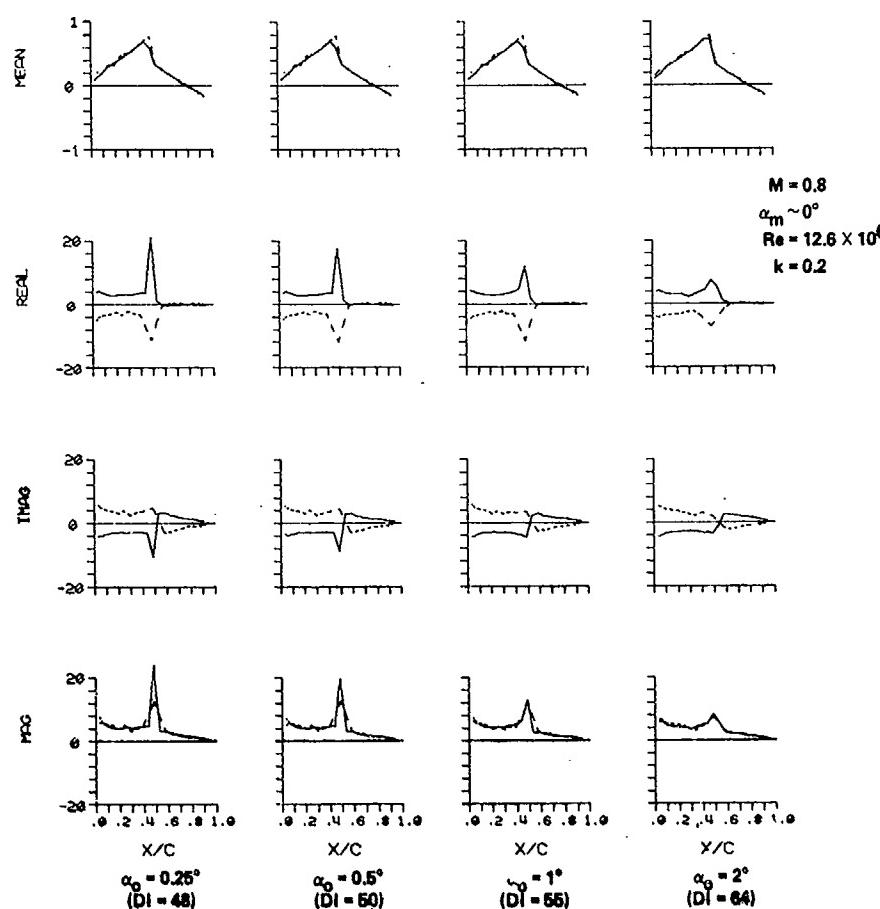


Fig. 2.3. Effect of varying oscillation amplitude.

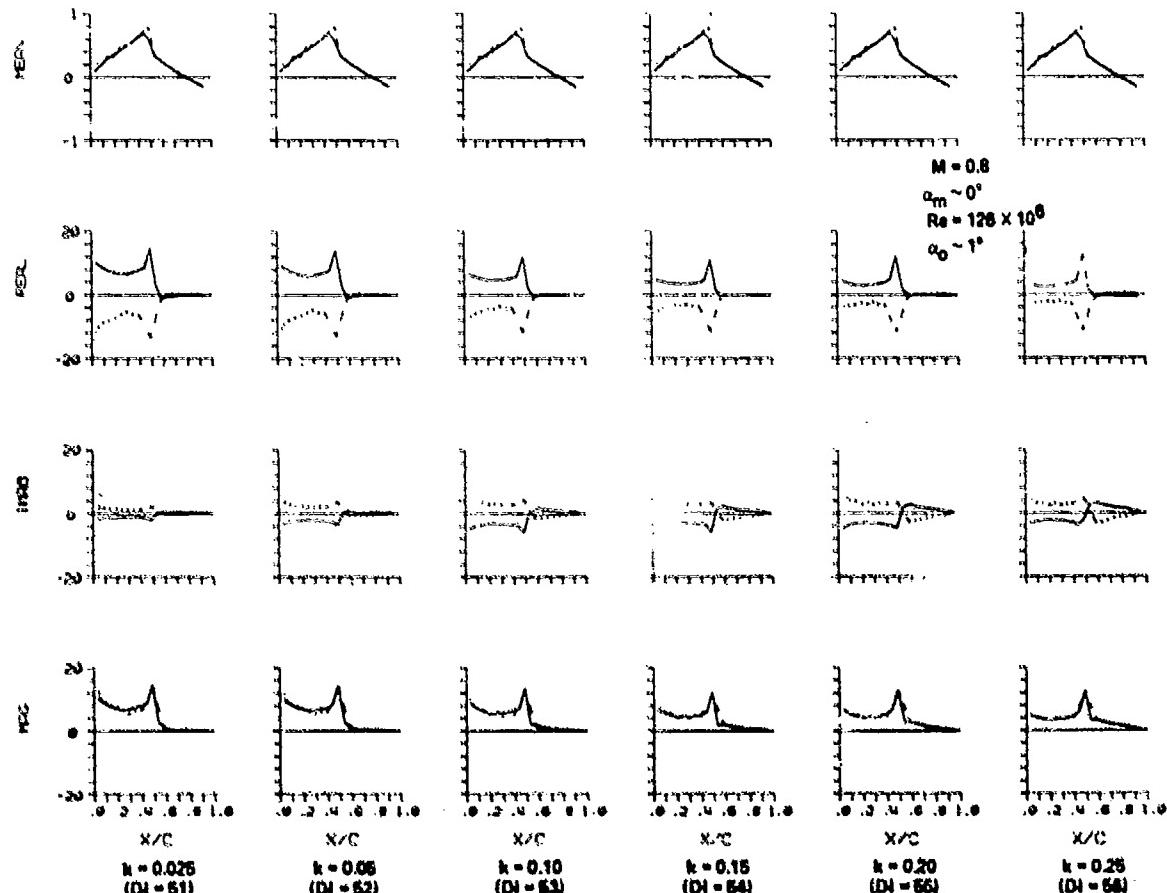


Fig. 2.4. Effect of varying frequency parameter.

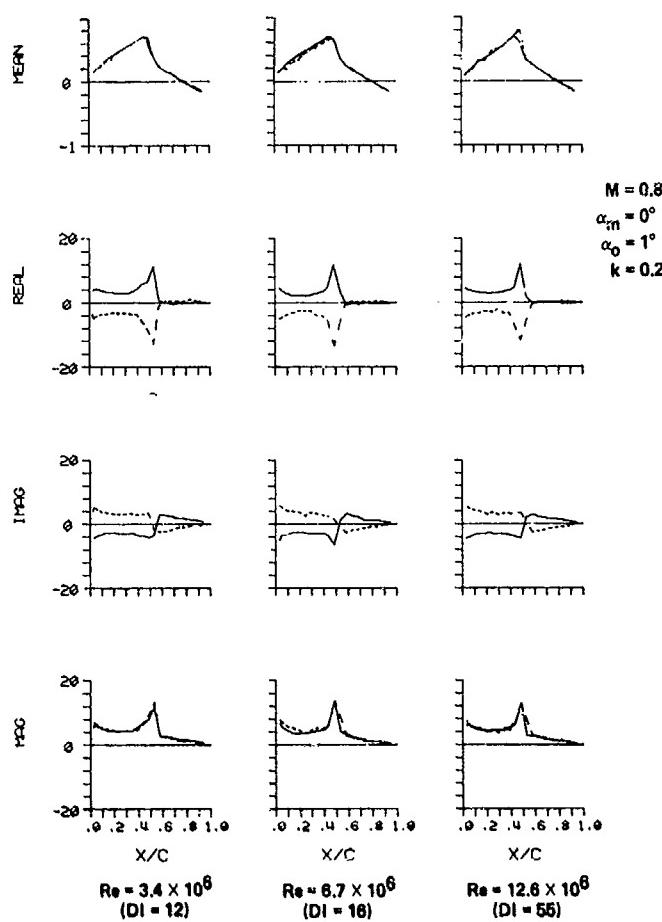


Fig. 2.5. Effect of varying Reynolds number.

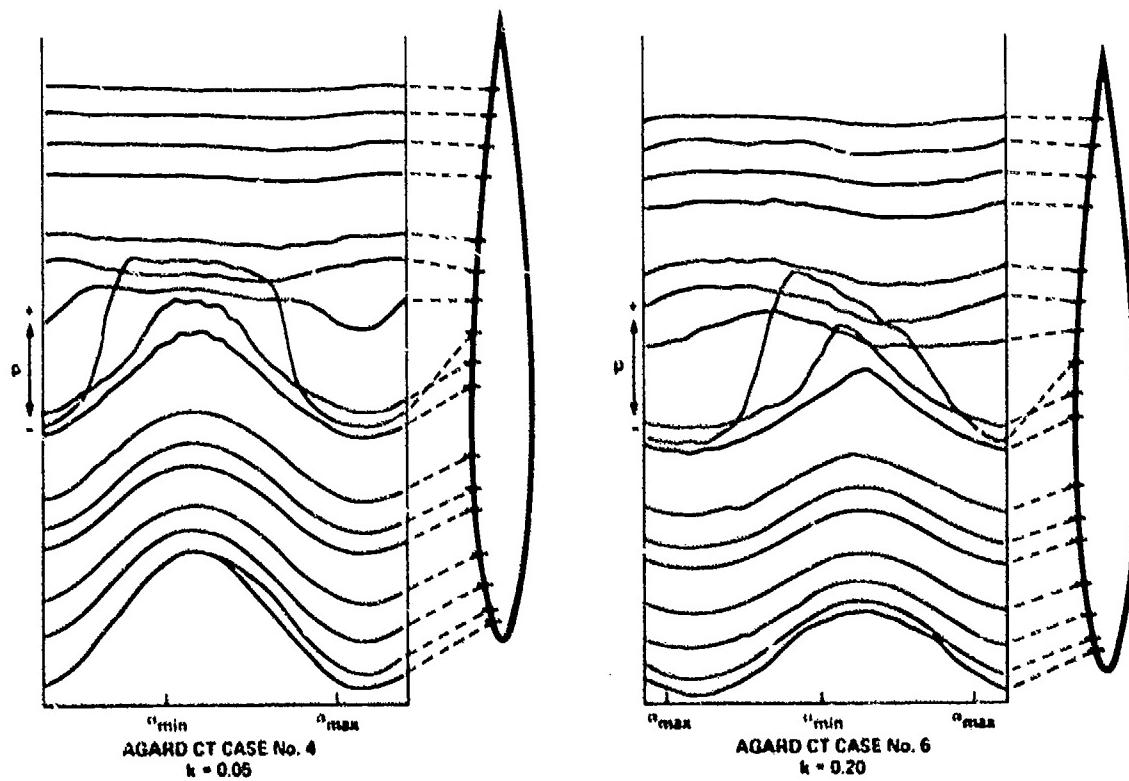


Fig. 2.6. Unsteady pressure time-histories for AGARD CT Cases 4 and 6.
 $M = 0.8, \alpha_m = 0^\circ$.

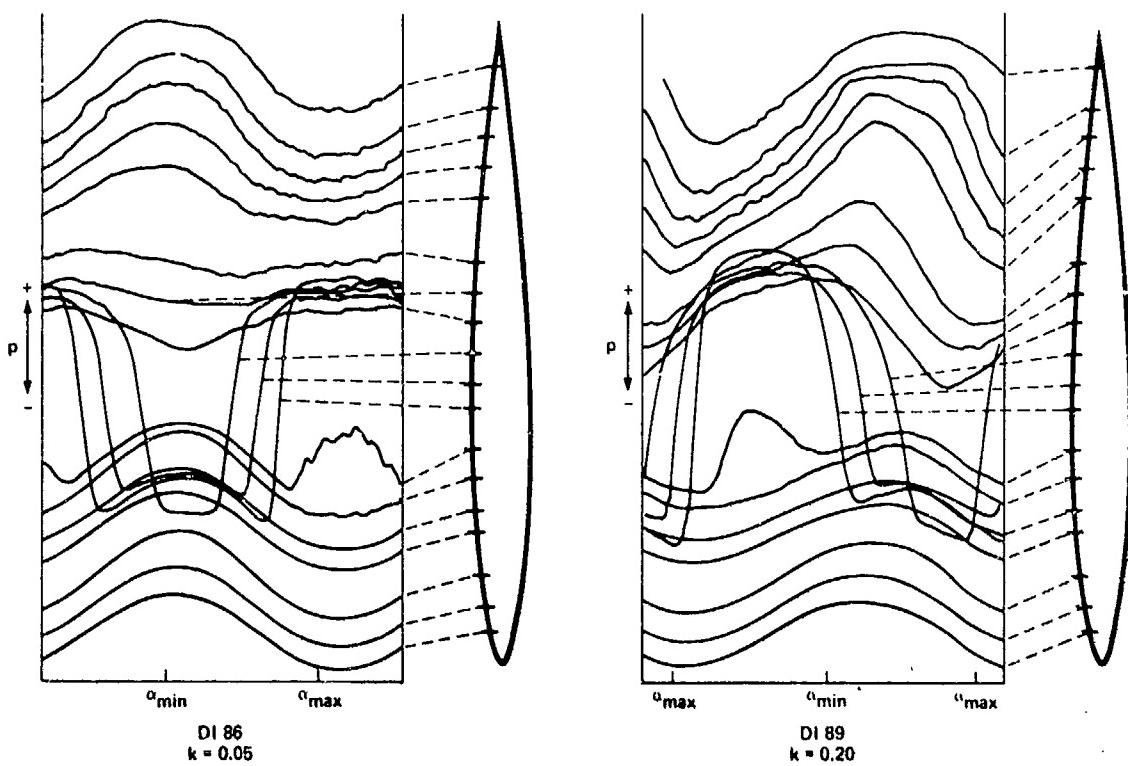


Fig. 2.7. Unsteady pressure time-histories for shock-stall case.
 $M = 0.8, \alpha_m = 4.0^\circ$.

DATA SET 3

NACA 0012. OSCILLATORY AND TRANSIENT PITCHING

by

R. H. Landon, ARA

INTRODUCTION

These results are extracted from tabulations of wing pressures resulting from the 3rd series of pitching tests about $0.25c$ axis made in the ARA 2-dimensional tunnel, using the pitching and heaving rig, Ref 3.1.

The main purpose of these tests was to examine the conditions of dynamic stall and recovery at scaled time rates similar to those of a typical helicopter application. Dynamic similarity was maintained also in Reynolds number; the approximately quarter scale blade section was therefore run, for all the cases reported here, at a tunnel stagnation pressure of 4 bar to match low altitude flight of the helicopter. Consequently, no artificial boundary layer transition trips were applied to the test wing.

The output of dynamic pressure transducers was sampled at fixed intervals, the instantaneous pressures and reference conditions having a matched and filtered response within 3 dB up to 460 Hz.

The results represent one specific cycle, and are not averaged over a number of cycles. The data bank at ARA contains at least 4 cycles of each dynamic condition. Ramp motions have only a single transient.

Up to 6 increments of mean incidence and amplitude, singly or in combination, could be run: the present programme called for 3 increments (called programme steps or PSTEP) of mean incidence, a_m as shown in Table 3.4.

The time-dependent results are presented without harmonic or spectral analysis. Note that the harmonic content of the pitching motion is relatively high, due to the intrusion of other modes of the drive system:

AGARD case	f (Hz)	Harmonic content and phase angle relative to the fundamental			
		First	Second	Third	Fourth
1,2,3	50.32	2.44°, -10°	2.45°, -39°	0.5°, -51°	0.38°, 0°
5	62.5	0.22°, -13°	2.60°, -44°	0.37°, -51°	0.07°, -76°

The instantaneous Mach number varies in sympathy with the drag of the wing: the flow momentum loss changes the effective area of the choked throat that controls the flow downstream of the model, thus making speed dependent on drag. Mach number is thus given for each data point in the results.

The heave mode (no results presented here) allowed the wing to be placed up to 63.5 mm (2.5 in) above and below the tunnel centre line. Some pitching tests are reported in Ref 3.2 to show possible effects on dynamic readings of wall proximity: there has been no analysis of unsteady tunnel interference, but corrections appropriate to steady interference have been applied to some of the measured quantities.

Notes on the data

The ordinates of the NACA 0012 airfoil are given in Table 3.1. The chordwise and spanwise locations of the 30 pressure holes and their channel numbers are given in Table 3.2, and the arrangement of the data is explained in Table 3.3.

Ten data sets are presented to provide experimental comparison with AGARD CT Cases. These are extracted from the full set of tests identified in Tables 3.4 and 3.5.

For the priority CT Case 1 the tabulated data are presented as 32 sets of pressure coefficients at equal time intervals during a cycle of oscillation, extracted from 64 sets in the original data. For the other CT Cases of oscillatory pitch the number is reduced to 8 sets. The ramp motion and quasi-steady data have 16 points, chosen to give approximately equal incidence increments, again taken from more closely spaced original data. Tables 3.7 to 3.10 include a pitch damping factor which is irrelevant for the present purpose and its value is also shown in each of the oscillatory plots. Note also that the ramp incidence rate is an approximate or nominal value: the incidence rate $\dot{a} = da/dt$ is not constant, and when calculated from different ranges of incidences, will give different values. Approximate representations of the motions in Ref 3.6 are recommended for comparative calculations at given a . No measurements were made for

strictly steady conditions, but instantaneous pressures were measured for very slow oscillations of incidence. The results of three of these quasi-steady tests are given in Tables 3.14 to 3.16.

Oscillatory pitch about 0.25c:

Related AGARD CT Case	Run No. and P step	Experimental conditions							Data table
		M	α_m (deg)	α_0 (deg)	f (Hz)	k	$Re \times 10^{-6}$	Sets	
1	87-1	0.600	2.89	2.41	50.32	0.0808	4.8	32	3.7
2	89-1	0.600	3.16	4.59	50.32	0.0811	4.8	8	3.8
3	87-3	0.600	4.86	2.44	50.32	0.0810	4.8	8	3.9
5	128-1	0.755	0.016	2.51	62.5	0.0814	5.5	8	3.10

Ramp motion about 0.25c:

Related AGARD CT Case	Run No.	Experimental conditions					Data table
		M	α range (deg)	$Re \times 10^{-6}$	Approx $\dot{\alpha}$ (deg/s)	Sets	
6	218	0.30	-0.03 to 15.54	2.7	1280	16	3.11
7	227	0.57	-0.01 to 14.80	4.6	425	16	3.12
8	230	0.56	-0.01 to 14.97	4.5	1380	16	3.13

Quasi-steady:

Run No.	M	α range in table (deg)	$Re \times 10^{-6}$	Sets	Data table
6	0.30	-0.12 to 15.55	2.6	16	3.14
11	0.58	-0.13 to 11.56	4.6	16	3.15
151	0.75	-3.27 to 3.35	5.5	16	3.16

Figs 3.2 to 3.4 show typical results extracted from Ref 3.2 for oscillatory pitching at $M = 0.6$ and 0.75 , showing the effect of reduced frequency parameter on normal force, pitching moment and a damping factor DF. The related AGARD CT cases 1, 2, 3 and 5 are included in these figures. Figs 3.2 and 3.3 are for respective amplitudes $\alpha_0 = 2.5^\circ$ and 5.0° .

Fig 3.5 shows curves of C_N against α from the quasi-steady data and for the two ramp rates at $M = 0.57$ to illustrate the lag in the growth of C_N and the delayed stall under dynamic conditions.

1 AIRFOIL

- 1.1 Designation NACA 0012
- 1.2 Type of airfoil Symmetrical 12% thick
- 1.3 Geometry See Table 3.1 and formula in Ref 3.6
- 1.4 Design condition -
- 1.5 Additional remarks -
- 1.6 References on airfoil Refs 3.6, 3.7

2 MODEL GEOMETRY

- 2.1 Chord length 101.6 mm (4 in)
- 2.2 Span 203.2 mm (8 in)
- 2.3 Actual model coordinates and accuracy of measurements See Fig 3.1 and Table 3.1. TE thickness = 0.383 mm, ie approximately 0.127 mm too thick
- 2.4 Flap: hinge and gap details -
- 2.5 Additional remarks -
- 2.6 References on model -

3	WIND TUNNEL	
3.1	Designation	ARA 2-dimensional tunnel
3.2	Type of tunnel	Intermittent blow down
3.3	Test section dimensions	$h = 457.2$, $b = 203.2$, length = 1251 mm
3.4	Type of roof and floor	Slotted, 3.2% open area ratio
3.5	Type of side walls	Solid
3.6	Ventilation geometry	Roof and floor each have 6 slots and 2 half slots at corners. Plenum chambers 133 mm deep connected by large ducts. Top and bottom walls diverge.
3.7	Thickness of side wall boundary layer	$2\delta^*/b = 0.015$
3.8	Thickness of boundary layers at roof and floor	Not known
3.9	Method of measuring Mach number	Static hole in side wall 5 chords ahead of model
3.10	Uniformity of Mach number over test section	Centre line distribution within ± 0.0015 in region of model
3.11	Sources and levels of noise or turbulence in empty tunnel	No serious disturbances
3.12	Tunnel resonances	No evidence
3.13	Additional remarks	
3.14	References on tunnel	Ref 3.8
4	MODEL MOTION	
4.1	Mode of applied motion	Pitching about 0.25c, oscillation or ramp. No heave results
4.2	Range of amplitude	Oscillation $\pm 9.5^\circ$; ramp 0 to 30° (limit 44°)
4.3	Range of frequency	0 to 60 Hz (limit 100 Hz)
4.4	Method of application	Hydraulic actuator
4.5	Purity of applied motion	See Introduction
4.6	Natural frequencies and normal modes of model	Lowest is bending at 600 Hz
4.7	Static or dynamic elastic distortion during tests	No significant distortion
4.8	Additional remarks	-
5	TEST CONDITIONS	
5.1	Tunnel height/model chord ratio	4.5
5.2	Tunnel width/model chord ratio	2.0
5.3	Range of Mach number	0.3 to 0.87
5.4	Range of tunnel total pressure	14-4 bar
5.5	Range of tunnel total temperature	280 K approximately, uncontrolled
5.6	Range of model steady, or mean, incidence	± 11 deg (limit 44°)
5.7	Definition of model incidence	On chordline: datum matched on chordwise pressure distributions
5.8	Position of transition, if free	Not known
5.9	Position and type of trip, if transition fixed	No trips in presented data because model is consistent with full-size helicopter blade
5.10	For mixed flow, position of sonic boundary in relation to roof and floor	-
5.11	Flow instabilities during tests	No simple answer: refer to ARA
5.12	Additional remarks	Position of model 0.25c is 5 chords downstream of start of slots
5.13	References describing tests	Refs 3.1, 3.2

6 MEASUREMENTS AND OBSERVATIONS

6.1	Steady pressures for the mean conditions	-
6.2	Steady pressures for small changes from the mean conditions	-
6.3	Quasi-steady pressures	✓
6.4	Unsteady pressures	✓
6.5	Steady forces for the mean conditions	measured directly
		integrated pressures
6.6	Steady forces for small changes from the mean conditions	measured directly
		integrated pressures
6.7	Quasi-steady forces	measured directly
		integrated pressures
6.8	Unsteady forces	measured directly
		integrated pressures
6.9	Measurement of actual motion at points on model	-
6.10	Observation or measurement of boundary layer properties	-
6.11	Visualization of surface flow	-
6.12	Visualization of shockwave movements	-
6.13	Additional remarks	-

7 INSTRUMENTATION

7.1	Steady pressures	Pressures for quasi-steady conditions measured with same system used for unsteady pressures
7.1.1	Position of orifices spanwise and chordwise	-
7.1.2	Type of measuring system	-
7.2	Unsteady pressures	
7.2.1	Position of orifices spanwise and chordwise	See Table 3.2
7.2.2	Diameter of orifices	0.25 mm
7.2.3	Type of measuring system	30 transducers in model (see Ref 3.1)
7.2.4	Type of transducers	Kulite XQCL absolute
7.2.5	Principle and accuracy of calibration	Calibrated under steady conditions against Texas Quartz Pressure Test Set. Accuracy: ±2.7 mb
7.3	Nodal motion	
7.3.1	Method of measurement	Shaft encoder
7.3.2	Accuracy	Resolution: ±0.1 deg
7.4	Processing of unsteady measurements	
7.4.1	Method of acquiring and processing measurements	Signals sampled at known time intervals, same points in cycle
7.4.2	Type of analysis	Instantaneous pressures reduced to non-dimensional coefficients
7.4.3	Unsteady pressure quantities obtained and accuracies achieved	Approximately ±0.01 in C_p
7.4.4	Method of integration to obtain forces	Standard curve fitting procedure
7.5	Additional remarks	Tabulated C_N and C_m are corrected for wall constraint
7.6	References on techniques	Refs 3.1, 3.9, 3.10

8 DATA PRESENTATION

- | | | |
|------|---|-------------------------|
| 8.1 | Test cases for which data could be made available | Tables 3.4, 3.5, 3.6 |
| 8.2 | Test cases for which data are included in this document | See Introduction |
| 8.3 | Steady pressures | - |
| 8.4 | Quasi-steady or steady perturbation pressures | Tables 3.14, 3.15, 3.16 |
| 8.5 | Unsteady pressures | Tables 3.7 to 3.13 |
| 8.6 | Steady forces or moments | - |
| 8.7 | Quasi-steady or steady perturbation forces | Tables 3.14, 3.15, 3.16 |
| 8.8 | Unsteady forces and moments | Tables 3.7 to 3.13 |
| 8.9 | Other forms in which data could be made available if required | None |
| 8.10 | References giving other presentations of data | Ref 3.1 |

9 COMMENTS ON DATA

- | | | |
|-------|--|--|
| 9.1 | Accuracy | |
| 9.1.1 | Mach number | ± 0.0015 |
| 9.1.2 | Steady incidence | Instantaneous incidence to ± 0.1 deg |
| 9.1.3 | Reduced frequency | Within about 1% |
| 9.1.4 | Steady pressure coefficients | - |
| 9.1.5 | Steady pressure derivatives | - |
| 9.1.6 | Unsteady pressure coefficients | Instantaneous C_p to ± 0.01 (see Ref 3.10) |
| 9.2 | Sensitivity to small changes of parameter | - |
| 9.3 | Spanwise variations | Not serious for data presented here (for other cases see Ref 3.1) |
| 9.4 | Non-linearities | - |
| 9.5 | Influence of tunnel total pressure | - |
| 9.6 | Wall interference corrections | Values of a , a_m , a_0 , C_N and C_m have been corrected on the basis of steady calibrations (see para 12). No corrections appear to be necessary for M . |
| 9.7 | Other relevant tests on same model | - |
| 9.8 | Relevant tests on other models of nominally the same aerofoil | Ref 3.11 gives steady measurements on another model of NACA 0012 in same tunnel |
| 9.9 | Any remarks relevant to comparison between experiment and theory | - |
| 9.10 | Additional remarks | - |
| 9.11 | References on discussion of data | Ref 3.2 |

10 PERSONAL CONTACT FOR FURTHER INFORMATION

Mr R.H. Landon, Aircraft Research Association Ltd, Manton Lane, Bedford MK41 7PF, England

11 LIST OF REFERENCES

- | | | |
|-----|---------------|--|
| 3.1 | R.H. Landon | A description of the ARA 2-dimensional pitch and heave rig and some results from the NACA 0012 wing.
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| 3.2 | Mrs M.E. Wood | Results of oscillatory pitch and ramp tests on the NACA 0012 blade section.
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- 3.3 A. Harris Calibration of ARA's 2-dimensional facility using 2.8% open area liners.
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Item 5, Tech Comm., June 1973
- 3.6 Ed. S.R. Bland AGARD two-dimensional aeroelastic configurations.
AGARD-AR-156, 1979
- 3.7 I.H. Abbott
A.E. von Doenhoff Theory of wing sections: including a summary of airfoil data.
McGraw-Hill, New York, 1949
- 3.8 R.L.F. Hammond Some notes on model testing in the ARA 2-dimensional facility.
ARA Memo 170, 1975
- 3.9 R.H. Landon
Mrs M.E. Wood Some sources of error with Kulite pressure transducers in the ARA pitch/heave rig.
ARA Memo 204, 1978
- 3.10 R.H. Landon
Mrs M.E. Wood The pitch/heave rig data selection and reduction program, and Corrigendum.
ARA Memo 182, 1976
- 3.11 Mrs J. Sawyer Results of tests on aerofoil M.102/9 (NACA 0012) in the ARA 2-dimensional tunnel.
ARA Model Test Note M.102/9, 1978

12 DEFINITIONS AND EXPLANATION OF DATA TABLES

- b airfoil span and tunnel width
- c chord
- C_N normal force coefficient
- C_m pitching moment coefficient (about 0.25c)
- f frequency (Hz)
- h tunnel height
- k reduced frequency, $\omega c/2V$
- M Mach number
- q dynamic pressure
- R, Re Reynolds number
- t time (seconds)
- v velocity
- x,y,z airfoil coordinates
- α incidence
- α_m mean incidence
- α_0 pitch amplitude
- δ^* displacement thickness of boundary layer
- ω frequency (rad/s)

For each chosen case, experimental data are presented as sets of instantaneous values of the quantities C_p , C_N , C_m , α and M for particular times t (in seconds) in Tables 3.7 to 3.16.

Uncorrected coefficients C'_N and C'_m are evaluated by a curve fitting procedure from the integrals

$$C'_N = \int_0^1 (C_{pL} - C_{pU}) d(x/c)$$

$$C'_m = \int_0^1 (C_{pL} - C_{pU}) (0.25 - (x/c)) d(x/c)$$

where $C_p = (p - p_\infty)/q$ is uncorrected and the suffices L and U denote lower and upper surfaces respectively.

Oscillatory motion is defined by

$$\alpha = \alpha_m + \alpha_0 \sin(\omega t + \epsilon)$$

where ϵ is a phase angle dependent on the time datum.

The quantities α , α_m , α_0 , C_N and C_m (but not C_p) have each been corrected for tunnel constraint effects. The corrections, as derived for steady conditions in Refs 3.3, 3.4 and 3.5, are applied to each instantaneous condition as if it were steady.

Table 3.1
NACA 0012 SECTION ORDINATES

x/c	z/c
0	0
0.0050	±0.01221
0.0125	±0.01894
0.0250	±0.02615
0.0500	±0.03555
0.0750	±0.04200
0.1000	±0.04683
0.1500	±0.05345
0.2000	±0.05738
0.2500	±0.05941
0.3000	±0.06002
0.3500	±0.05949
0.4000	±0.05803
0.4500	±0.05581
0.5000	±0.05294
0.5500	±0.04952
0.6000	±0.04563
0.6500	±0.04132
0.7000	±0.03664
0.7500	±0.03160
0.8000	±0.02623
0.8500	±0.02053
0.9000	±0.01448
0.9500	±0.00807
1.0000	±0.00126

Table 3.2
NACA 0012 WING PRESSURE LOCATIONS AND CHANNEL NUMBER IDENTITIES

Upper surface			Lower surface		
Channel No.	x/c	y/b	Channel No.	x/c	y/b
1	1.0 TE	0.52	21	0 LE	0.44
2	0.9	0.51	22	0.01	0.46
3	0.8	0.48	23	0.02	0.48
4	0.7	0.49	24	0.04	0.48
5	0.6	0.5	25	0.10	0.48
6	0.5	0.5	26	0.22	0.5
7	0.4	0.5	27	0.34	0.5
8	0.3	0.5	28	0.46	0.5
9	0.2	0.51	29	0.57	0.5
10	0.15	0.48	30	0.68	0.5
11	0.125	0.48	31	0.79	0.54
12	0.1	0.49	32	0.90	0.55
13	0.075	0.5			
14	0.05	0.51			
15	0.03	0.52			
16	0.02	0.53			
17	0.01	0.55			
18	0.005	0.56			

Table 3.3
LAYOUT OF RESULTS IN TABLES 3.7 TO 3.16

c_{p1}	c_{p2}	c_{p3}	c_{p4}	c_{p5}	c_{p6}	c_{p7}	c_{p8}	c_{p9}	c_{p10}	Data point	
c_{p11}	c_{p12}	c_{p13}	c_{p14}	c_{p15}	c_{p16}	c_{p17}	c_{p18}	c_{p21}	c_{p22}	M	c_N
c_{p23}	c_{p24}	c_{p25}	c_{p26}	c_{p27}	c_{p28}	c_{p29}	c_{p30}	c_{p31}	c_{p32}	t (second)	c_m
								$q \text{ (lb/ft}^2\text{)}$		$\alpha \text{ (deg)}$	

where, in the arrangement above, c_{pn} is the instantaneous value of c_p for channel n (see Table 3.2). Corresponding x/c locations can be identified from the following key:

<u>Upper</u>									
1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.10	0.15
<u>Upper</u>									
0.125	0.10	0.075	0.05	0.03	0.02	0.01	0.005	0	0.01
<u>Lower</u>									
0.02	0.04	0.10	0.22	0.34	0.46	0.57	0.68	0.79	0.90

Table 3.4
PARAMETERS OF OSCILLATORY PITCH CASES

ARA run No.	M	α_0 (deg)	α_m (deg)	f (Hz)	k	$Re \times 10^{-6}$	ARA run No.	M	α_0 (deg)	α_m (deg)	f (Hz)	k	$Re \times 10^{-6}$
152	0.288	8.5	4,5,6	30	0.099	2.7	178	0.598	2.5	3,4,5	30	0.050	4.9
153	0.286	8.5	7,8,9	30	0.099	2.7	179	0.593	2.5	6,8,10	30	0.050	4.9
183	0.287	8.5	10,11,12	30	0.101	2.7	180	0.597	5.0	3,4,5	30	0.050	4.9
184	0.286	7.5	6	30	0.102	2.7	202	0.600	5.0	6,9,12	30	0.049	5.0
156	0.292	9.5	6	30	0.096	2.7	87	0.600	2.5	3,4,5	50	0.081	4.9
185	0.287	9.5	6	30	0.102	2.7	88	0.595	2.5	6,8,10	50	0.082	4.9
186	0.285	Max	6	30	0.102	2.7	90	0.598	5.0	3,4,5	50	0.082	4.9
157	0.290	2.5	9,10,11	30	0.097	2.7	91	0.599	2.5	3,4,5	70	0.115	4.9
158	0.286	2.5	12,14,16	30	0.099	2.7	92	0.594	2.5	6,8,10	70	0.116	4.9
159	0.288	5.0	9,10,11	30	0.098	2.7	93	0.599	5.0	3,4,5	70	0.115	4.9
160	0.286	5.0	12,15,18	30	0.099	2.7	94	0.591	5.0	6,9,12	70	0.117	4.9
199	0.305	2.5	9,10,11	50	0.155	2.8	103	0.699	2.5	1,2,3	29	0.041	5.4
200	0.298	2.5	9,10,11	50	0.159	2.8	96	0.688	2.5	4,6,8	29	0.042	5.4
188	0.285	2.5	12,14,16	50	0.168	2.6	104	0.697	5.0	1,2,3	29	0.041	5.4
39	0.290	5.0	9,10,11	50	0.170	2.7	98	0.686	5.0	4,6,8	29	0.042	5.4
40	0.287	5.0	12,15,18	50	0.172	2.7	105	0.699	2.5	1,2,3	58	0.081	5.5
116	0.287	2.5	9,10,11	70	0.238	2.7	100	0.686	2.5	4,6,8	58	0.083	5.4
43	0.289	2.5	12,14,16	70	0.245	2.7	106	0.696	5.0	1,2,3	58	0.082	5.4
117	0.292	5.0	9,10,11	70	0.231	2.7	102	0.685	5.0	4,6,8	58	0.083	5.4
44	0.287	5.0	12,15,18	70	0.245	2.7	122	0.700	2.5	1,2,3	80	0.115	5.5
161	0.382	8.5	2,3,4	30	0.075	3.5	123	0.691	2.5	4,6,8	80	0.116	5.4
162	0.380	8.5	5,6,7	30	0.075	3.5	124	0.698	5.0	1,2,3	70	0.101	5.5
163	0.379	8.5	8,9,10	30	0.076	3.5	125	0.691	5.0	4,6,8	70	0.101	5.4
164	0.380	7.5	4	30	0.076	3.5	95	0.699	2.5	0,1,2	29	0.041	5.4
165	0.380	9.5	4	30	0.076	3.5	97	0.696	5.0	0,1,2	29	0.041	5.4
166	0.380	Max	4	30	0.076	3.5	99	0.697	2.5	0,1,2	58	0.082	5.4
201	0.398	2.5	3,9	30	0.073	3.6	101	0.693	5.0	0,1,2	58	0.082	5.4
168	0.377	2.5	10,12,14	30	0.077	3.4	126	0.754	2.5	0,1,2	31	0.042	5.7
169	0.379	5.0	6,8,10	30	0.076	3.4	127	0.744	2.5	3,4,5	31	0.042	5.6
170	0.377	5.0	9,12,15	30	0.077	3.4	128	0.753	2.5	0,1,2	62	0.082	5.7
59	0.377	2.5	7,8,9	50	0.126	3.3	129	0.743	2.5	3,4,5	62	0.083	5.6
60	0.383	2.5	10,12,14	50	0.128	3.3	130	0.753	2.5	0,1,2	80	0.108	5.7
61	0.380	5.0	6,8,10	50	0.127	3.4	131	0.744	2.5	3,4,5	80	0.108	5.6
62	0.380	5.0	9,12,15	50	0.128	3.4	138	0.805	2.5	0,1,1	33	0.041	5.9
63	0.381	2.5	7,8,9	70	0.182	3.5	203	0.816	2.5	0,1,1	33	0.041	6.0
64	0.378	2.5	10,12,14	70	0.184	3.4	204	0.802	2.5	0,1,1	33	0.041	6.0
65	0.378	5.0	6,8,10	70	0.184	3.4	139	0.794	2.5	2,2,3	33	0.041	5.8
66	0.378	5.0	9,12,15	70	0.184	3.4	134	0.785	2.5	0,1,1	66	0.082	5.8
171	0.483	8.5	0,1,2	30	0.060	4.2	135	0.792	2.5	2,2,3	66	0.081	5.8
172	0.482	8.5	3,4,5	30	0.060	4.2	136	0.799	2.5	0,1,1	80	0.101	5.9
173	0.482	8.5	6,7,8	30	0.060	4.2	137	0.794	2.5	2,2,3	80	0.102	5.9
174	0.483	2.5	5,6,7	30	0.060	4.2	142	0.814	2.5	0,1,2	80	0.100	5.9
175	0.481	2.5	8,10,12	30	0.061	4.2	141	0.821	2.5	0,1,2	80	0.099	5.9
176	0.483	5.0	5,6,7	30	0.060	4.2	143	0.829	2.5	0,1,2	80	0.098	6.0
177	0.479	5.0	9,12,15	30	0.061	4.2	144	0.840	2.5	0,1,2	80	0.097	5.9
107	0.484	2.5	5,6,7	50	0.100	4.2	145	0.866	2.5	0,1,2	80	0.094	6.0
108	0.481	2.5	8,10,12	50	0.101	4.2	146	0.878	2.5	0,1,2	80	0.093	6.0
119	0.489	5.0	5,6,7	50	0.099	4.2	147	0.896	2.5	0,1,2	80	0.092	6.0
109	0.479	5.0	9,12,15	50	0.101	4.1							
78	0.480	2.5	5,6,7	70	0.147	4.2							
118	0.488	2.5	8,10,12	70	0.141	4.2							
80	0.480	5.0	5,6,7	70	0.147	4.2							
81	0.476	5.0	9,12,15	70	0.149	4.2							

Table 3.5
PARAMETERS OF RAMP PITCH CASES

ARA run No.		α° range	$\frac{da}{dt}$ (deg/s)	$Re \times 10^{-6}$
215	0.296	0-30	400	2.7
216	0.298	0-30	800	2.7
242	0.299	0-30	1200	2.7
218	0.294	0-30	1600	2.7
214	0.406	0-30	400	3.5
243	0.410	0-30	800	3.5
222	0.410	0-30	1200	3.6
219	0.412	0-30	1600	3.6
223	0.504	0-30	400	4.2
224	0.501	0-30	800	4.2
225	0.503	0-30	1200	4.2
226	0.496	0-30	1600	4.2
227	0.613	0-30	400	4.8
228	0.615	0-30	800	4.8
229	0.614	0-30	1200	4.8
230	0.611	0-30	1600	4.7
231	0.707	0-30	800	5.2
232	0.706	0-30	1600	5.2
233	0.761	0-30	1600	5.3
234	0.760	0-30	800	5.3
235	0.806	0-30	800	5.5
237	0.809	0-30	1600	5.5
239	0.834	0-30	800	5.7
238	0.838	0-30	1600	5.4
240	0.900	0-30	800	5.9
241	0.902	0-30	1600	5.9
236	0.812	0-30	800	5.5

Table 3.6
PARAMETERS OF QUASI-STEADY CASES

N	ARA run No.	α_0 (deg)	α_m (deg)	N	ARA run No.	α_0 (deg)	α_m (deg)
0.3	6	11	11	0.75	14	5	5
0.3	189	11	11	0.75	192	5	5
0.3	278	11	11	0.8	15	4	4
0.4	7	11	11	0.8	193	4	4
0.4	245	11	11	0.8	296	4	4
0.45	190	11	11				
0.5	9	10	10	0.4	148	0	11
0.5	279	10	10	0.6	149	0	9
0.55	46	10	10	0.7	150	0	7
0.6	11	9	9	0.75	151	0	5
0.6	280	9	9	0.3	244	0	11
0.65	12	8	8	0.5	246	0	10
0.65	191	8	8	0.6	247	0	8
0.7	13	7	7	0.7	248	0	7
0.7	281	7	7	0.8	249	0	4

Table 3.7

ARA RUN 87 PSTEP 1 AGARD CASE 1 - OSC. PITCH											
M=0.6 R=4.8*10 ⁶ ωc/2v=0.0808 ᾱm=2.89 ᾱo=2.41 Damping +0.06708											
0.1647	-0.0007	-0.1408	-0.2437	-0.3383	-0.4547	-0.5712	-0.7231	-0.8666	-0.9290	2	
-1.0117	-1.0640	-1.1383	-1.1316	-1.1096	-0.9442	-0.7231	-0.5408	0.9766	0.6306	0.602	0.3719
0.3993	0.1580	-0.1897	-0.2468	-0.2454	-0.1948	-0.1560	-0.1070	-0.0530	0.0263	0.00000	0.0014
										1706.3	2.97
0.1562	-0.0024	-0.1493	-0.2539	-0.3501	-0.4716	-0.5969	-0.7535	-0.9172	-0.9965	4	
-1.0894	-1.1484	-1.2615	-1.2583	-1.0928	-0.8683	-0.6860	0.9191	0.7031	0.602	0.4267	
0.4752	0.2254	-0.1358	-0.2151	-0.2134	-0.1746	-0.1391	-0.0986	-0.0497	0.0263	0.00062	0.0022
										1706.3	3.42
0.1645	0.0044	-0.1439	-0.2518	-0.3512	-0.4760	-0.6057	-0.7760	-0.9597	-1.0507	6	
-1.1519	-1.2277	-1.3979	-1.4097	-1.4148	-1.2328	-1.0103	-0.8316	0.8674	0.7747	0.602	0.4777
0.5455	0.2977	-0.0731	-0.1759	-0.1810	-0.1473	-0.1203	-0.0815	-0.0343	0.0348	0.00124	0.0043
										1708.7	3.84
0.1657	0.0078	-0.1416	-0.2519	-0.3571	-0.4879	-0.6304	-0.8070	-1.0107	-1.1024	8	
-1.2161	-1.3044	-1.5827	-1.5929	-1.5963	-1.3689	-1.1516	-0.9699	0.8138	0.8277	0.600	0.5285
0.6036	0.3538	-0.0312	-0.1348	-0.1568	-0.1314	-0.1059	-0.0720	-0.0261	0.0367	0.00187	0.0070
										1696.6	4.23
0.1594	0.0044	-0.1473	-0.2586	-0.3681	-0.4996	-0.6445	-0.8299	-1.0406	-1.1434	10	
-1.2446	-1.4333	-1.7570	-1.7772	-1.7182	-1.4772	-1.2581	-1.0878	0.7460	0.8572	0.602	0.5731
0.6449	0.4005	0.0094	-0.0968	-0.1389	-0.1187	-0.0984	-0.0647	-0.0260	0.0398	0.00249	0.0083
										1708.7	4.56
0.1632	0.0094	-0.1344	-0.2530	-0.3616	-0.4954	-0.6441	-0.8276	-1.0419	-1.1271	12	
-1.2191	-1.6887	-1.9077	-1.9043	-1.8024	-1.5817	-1.3528	-1.1940	0.6830	0.8936	0.605	0.6049
0.6880	0.4540	0.0529	-0.0641	-0.1143	-0.0976	-0.0825	-0.0558	-0.0173	0.0378	0.00311	0.0124
										1723.1	4.83
0.1537	-0.0008	-0.1571	-0.2721	-0.3871	-0.5211	-0.6807	-0.8730	-1.0791	-1.1237	14	
-1.4293	-1.9393	-2.0835	-2.0577	-1.9461	-1.7401	-1.4929	-1.3194	0.6413	0.9229	0.596	0.6485
0.7186	0.4782	0.0627	-0.0661	-0.1193	-0.1038	-0.0953	-0.0643	-0.0283	0.0301	0.00373	0.0149
										1677.4	4.90
0.1479	0.0043	-0.1473	-0.2675	-0.3803	-0.5205	-0.6778	-0.8710	-1.0556	-1.1018	16	
-1.8471	-2.0318	-2.1514	-2.1138	-1.9976	-1.8078	-1.5616	-1.3719	0.6010	0.9395	0.597	0.6717
0.7343	0.5001	0.0830	-0.0521	-0.1083	-0.0948	-0.0880	-0.0640	-0.0264	0.0300	0.00435	0.0189
										1684.6	5.11
0.1559	0.0111	-0.1387	-0.2548	-0.3659	-0.5005	-0.6520	-0.8389	-0.9887	-1.0863	18	
-2.0255	-2.0675	-2.1551	-2.1130	-2.0002	-1.8218	-1.5761	-1.3707	0.5750	0.9402	0.603	0.6729
0.7433	0.5127	0.1003	-0.0326	-0.0949	-0.0781	-0.0781	-0.0343	-0.0158	0.0364	0.00497	0.0208
										1711.1	5.09
0.1533	0.0094	-0.1429	-0.2580	-0.3697	-0.5119	-0.6643	-0.8904	-1.0926	-1.1213	20	
-2.0943	-2.1233	-2.1994	-2.1571	-2.0471	-1.8643	-1.6223	-1.3971	0.5646	0.9369	0.601	0.6736
0.7440	0.5087	0.0940	-0.0414	-0.1057	-0.1006	-0.0888	-0.0483	-0.0261	0.0297	0.00559	0.0236
										1701.8	5.05
0.1533	0.0061	-0.1430	-0.2545	-0.3642	-0.5065	-0.6591	-0.8443	-1.0918	-1.0792	22	
-2.1234	-2.1594	-2.2369	-2.1902	-2.0639	-1.8936	-1.6484	-1.4015	0.5737	0.9389	0.597	0.6694
0.7400	0.5034	0.0833	-0.0522	-0.1207	-0.1122	-0.0967	-0.0710	-0.0333	0.0301	0.00621	0.0254
										1579.7	4.82
0.1552	0.0077	-0.1381	-0.2482	-0.3567	-0.4940	-0.6432	-0.8313	-1.0906	-1.0923	24	
-1.9992	-2.1144	-2.1924	-2.1551	-2.0534	-1.8619	-1.6110	-1.3396	0.6037	0.9138	0.600	0.6422
0.7145	0.4755	0.0653	-0.0686	-0.1313	-0.1177	-0.1023	-0.0770	-0.0364	0.0347	0.00683	0.0262
										1699.1	4.54
0.1494	0.0009	-0.1426	-0.2523	-0.3603	-0.4936	-0.6354	-0.8244	-1.0101	-1.0320	26	
-1.4118	-2.0348	-2.1358	-2.1172	-2.0295	-1.8134	-1.5637	-1.2784	0.6237	0.8789	0.601	0.6039
0.6743	0.4363	0.0313	-0.0936	-0.1910	-0.1392	-0.1169	-0.0903	-0.0447	0.0194	0.00745	0.0238
										1703.4	4.17
0.1597	0.0112	-0.1373	-0.2449	-0.3524	-0.4873	-0.6236	-0.8168	-1.0216	-1.1070	28	
-1.0848	-1.9657	-2.0698	-2.0784	-2.0067	-1.7472	-1.4945	-1.2077	0.6889	0.8665	0.598	0.5739
0.6582	0.4124	0.0095	-0.1151	-0.1696	-0.1527	-0.1271	-0.0947	-0.0486	0.0231	0.00807	0.0238
										1687.0	3.80
0.1583	0.0077	-0.1328	-0.2411	-0.3427	-0.4747	-0.6067	-0.7870	-0.9892	-1.0897	30	
-1.1991	-1.9613	-1.9049	-1.9574	-1.9134	-1.6290	-1.3667	-1.0891	0.7358	0.8201	0.601	0.5269
0.6032	0.3598	0.0380	-0.1446	-0.1903	-0.1649	-0.1396	-0.1023	-0.0532	0.0179	0.00869	0.0220
										1701.9	3.40
0.1601	0.0094	-0.1294	-0.2309	-0.3342	-0.4611	-0.5898	-0.7658	-0.9588	-1.0485	32	
-1.1923	-1.2651	-1.6663	-1.7644	-1.8068	-1.4933	-1.2279	-0.9486	0.7914	0.7796	0.601	0.4768
0.5544	0.3107	0.0768	-0.1734	-0.2106	-0.1765	-0.1514	-0.1091	-0.0549	0.0179	0.00931	0.0192
										1701.9	3.01

(continued overleaf)

Table 3.7 (concluded)

Table 3.8

Table 3.9

Table 3.10

ARA	RUN	128	PSTEP	1	AGARD CASE	S	-	OSC	PITCH			
M=0.755	R=5.5*10 ⁶				$\omega_c/2\nu=0.0814$	$\bar{\alpha}_m=0.016$	$\bar{\alpha}_g=2.51$			Damping	+0.07790	
0.2056	0.0453	-0.0990	-0.2950	-0.2999	-0.4158	-0.5236	-0.8831	-0.8399	-0.8005		4	
-0.7376	-0.6636	-0.5773	-0.4466	-0.2851	-0.0681	0.1784	0.3634	1.1623	0.2413	0.754	0.1008	
-0.0003	-0.2284	-0.6316	-0.7290	-0.4183	-0.3517	-0.2555	-0.1594	-0.0718	0.0416	0.00000	-0.0074	
										2336.0	1.09	
0.2089	0.0551	-0.0803	-0.1751	-0.2600	-0.4778	-1.1719	-1.1411	-1.0537	-1.0242		8	
-0.9639	-0.8741	-0.7963	-0.6698	-0.5504	-0.3326	-0.0889	0.0944	1.1565	0.5129	0.755	0.3436	
0.2729	0.0341	-0.3424	-0.4249	-0.3818	-0.2735	-0.2071	-0.1295	-0.0532	0.0514	0.00200	-0.0056	
										2340.2	2.34	
0.1996	0.0807	-0.0370	-0.1204	-0.3522	-0.5938	-1.2310	-1.1995	-1.1272	-1.0794		12	
-1.0303	-0.9616	-0.8967	-0.7470	-0.6563	-0.4184	-0.1609	0.0267	1.1426	0.5700	0.757	0.4001	
0.3357	0.1015	-0.2786	-0.3779	-0.3595	-0.2713	-0.2124	-0.1388	-0.0567	0.0488	0.00399	-0.0013	
										2348.6	2.01	
0.2072	0.0713	-0.0460	-0.1152	-0.1794	-0.4018	-1.2010	-1.1442	-1.0602	-0.9984		16	
-0.9688	-0.9095	-0.8280	-0.7057	-0.5364	-0.2807	-0.0127	0.1899	1.1547	0.4308	0.753	0.2592	
0.1825	-0.0399	-0.4265	-0.5167	-0.4697	-0.3586	-0.2746	-0.1831	-0.0831	0.0330	0.00599	0.0126	
										2331.5	0.52	
0.2139	0.0613	-0.0618	-0.1480	-0.2243	-0.3154	-0.3400	-0.8619	-0.8471	-0.7695		20	
-0.7412	-0.6982	-0.6108	-0.4434	-0.2403	0.0010	0.2730	0.4749	1.1617	0.1758	0.755	-0.0021	
-0.0766	-0.2821	-0.6502	-0.7412	-0.6083	-0.4384	-0.3178	-0.2033	-0.0926	0.0404	0.00799	0.0138	
										2339.8	-1.25	
0.2057	0.0589	-0.0621	-0.1410	-0.2064	-0.2953	-0.3792	-0.4742	-0.4903	-0.4915		24	
-0.4606	-0.3989	-0.3187	-0.1472	0.0515	0.2933	0.5303	0.6981	1.1251	-0.1065	0.753	-0.2425	
-0.3582	-0.5088	-0.8679	-1.0357	-1.0739	-0.4668	-0.3076	-0.2040	-0.0991	0.0391	0.00999	0.0044	
										2333.9	-2.41	
0.2138	0.0634	-0.0565	-0.1408	-0.2093	-0.2839	-0.3634	-0.4417	-0.4283	-0.4258		28	
-0.3793	-0.3072	-0.2301	-0.0711	0.1148	0.3422	0.5856	0.7410	1.1066	-0.1788	0.758	-0.2911	
-0.4307	-0.3306	-0.9321	-1.0852	-1.1694	-0.5848	-0.2815	-0.1494	-0.0589	0.0573	0.01199	-0.0017	
										2354.8	-2.00	
0.2183	0.0562	-0.0763	-0.1709	-0.2519	-0.3488	-0.4458	-0.5624	-0.5600	-0.5428		32	
-0.5072	-0.4237	-0.3464	-0.1954	-0.0174	0.1937	0.4478	0.6111	1.1413	-0.0371	0.757	-0.1325	
-0.2924	-0.4603	-0.8239	-1.0134	-1.0645	-0.3366	-0.2187	-0.1463	-0.0567	0.0538	0.01399	-0.0108	
										2346.3	-0.54	

Table 3.11

ARA RUN 218 AGARD CASE 6 - RAMP
 $M=0.3$ $R=2.7 \times 10^6$ & $c/v=0.02545$ Rad

Table 3.12

AGARD CASE 7 - RAMP											
ARA	RUN	227	M=0.57	R=4.6*10 ⁶	αc/v=0.0044	Rad					
0.1899	0.0429	-0.0776	-0.1552	-0.2279	-0.3072	-0.3881	-0.4822	-0.5450	-0.5334	151	
-0.5979	-0.5648	-0.5599	-0.4806	-0.3501	-0.1354	0.0661	0.2874	1.1082	0.1107	0.613	0.0282
-0.1453	-0.3154	-0.5202	-0.4905	-0.4129	-0.3055	-0.2345	-0.1552	-0.0694	0.0347	0.00000	0.0018
										1743.8	-0.01
0.1933	0.0413	-0.0859	-0.1751	-0.2544	-0.3370	-0.4294	-0.5418	-0.6343	-0.6425	169	
-0.7235	-0.6871	-0.7069	-0.6557	-0.5434	-0.3551	-0.1553	0.0611	1.1133	0.3138	0.613	0.1363
0.0512	-0.1454	-0.3931	-0.3981	-0.3436	-0.2593	-0.1966	-0.1272	-0.0529	0.0429	0.00698	0.0014
										1743.6	0.98
0.1919	0.0410	-0.0935	-0.1854	-0.2723	-0.3707	-0.4790	-0.6184	-0.7382	-0.7693	180	
-0.8743	-0.8514	-0.9088	-0.8924	-0.8251	-0.6496	-0.4708	-0.2264	1.0826	0.5216	0.615	0.2540
0.2641	0.0377	-0.2575	-0.3035	-0.2789	-0.2116	-0.1624	-0.1066	-0.0344	0.0476	0.01126	0.0043
										1755.7	1.97
0.1885	0.0347	-0.1058	-0.2084	-0.3076	-0.4134	-0.5391	-0.7012	-0.8533	-0.9178	189	
-1.0468	-1.0501	-1.1527	-1.1725	-1.1510	-0.9823	-0.8136	-0.5689	1.0286	0.6946	0.612	0.3798
0.4432	0.2067	-0.1406	-0.2166	-0.2130	-0.1703	-0.1306	-0.0827	-0.0215	0.0496	0.01475	0.0059
										1741.5	2.93
0.1921	0.0331	-0.1143	-0.2219	-0.3295	-0.4488	-0.5945	-0.7733	-0.9737	-1.0664	197	
-1.2271	-1.2486	-1.4722	-1.4788	-1.5450	-1.3016	-1.1509	-0.9141	0.9356	0.8330	0.612	0.5050
0.5962	0.3511	-0.0265	-0.1292	-0.1507	-0.1225	-0.0927	-0.0546	-0.0050	0.0580	0.01786	0.0083
										1739.2	3.94
0.1805	0.0331	-0.1159	-0.2318	-0.3444	-0.4720	-0.6276	-0.8230	-1.0317	-1.1128	203	
-1.3496	-1.7586	-1.8216	-1.8696	-1.7901	-1.5699	-1.3993	-1.1724	0.8462	0.9191	0.612	0.6105
0.6988	0.4587	0.0696	-0.0530	-0.0977	-0.0828	-0.0629	-0.0348	0.0083	0.0613	0.02019	0.0129
										1739.2	4.79
0.1755	0.0315	-0.1176	-0.2335	-0.3944	-0.4852	-0.6376	-0.8214	-1.1377	-1.7603	210	
-2.1528	-2.1114	-2.1561	-2.1213	-2.0236	-1.8497	-1.6692	-1.4341	0.7203	0.9952	0.612	0.7425
0.7949	0.5746	0.1656	0.0199	-0.0364	-0.0381	-0.0315	-0.0116	0.0232	0.0662	0.02291	0.0212
										1739.2	5.79
0.1648	0.0250	-0.1232	-0.2398	-0.3580	-0.4843	-0.6211	-0.8923	-1.5152	-2.3228	216	
-2.4027	-2.3544	-2.3544	-2.3128	-2.2412	-2.0514	-1.8699	-1.6184	0.6074	1.0540	0.610	0.8628
0.8792	0.6694	0.2314	0.0899	0.0117	0.0017	-0.0017	0.0083	0.0366	0.0699	0.02923	0.0263
										1729.7	6.70
0.0747	-0.0000	-0.1279	-0.2408	-0.3753	-0.6027	-0.9083	-1.2254	-1.5575	-1.6854	223	
-1.7983	-2.3272	-2.9239	-2.4873	-2.4159	-2.2482	-2.0324	-1.9245	0.4666	1.0843	0.610	0.9873
0.9315	0.7336	0.3294	0.1461	0.0398	0.0349	0.0183	0.0199	0.0315	0.0465	0.02795	0.0153
										1734.5	7.75
-0.0616	-0.1083	-0.2664	-0.3912	-0.6026	-0.7075	-0.8224	-1.0421	-1.3784	-1.5898	229	
-1.7397	-2.0410	-2.6353	-2.6054	-2.5404	-2.3873	-2.1958	-2.1492	0.3446	1.1037	0.609	0.9878
0.9706	0.7774	0.3662	0.1798	0.0749	0.0383	0.0183	0.0017	0.0033	-0.0050	0.03028	-0.0102
										1730.0	8.73
-0.0789	-0.1527	-0.2467	-0.3296	-0.4163	-0.6143	-0.8325	-1.1749	-1.4704	-1.5912	235	
-1.6265	-1.7093	-2.1162	-2.6117	-2.6470	-2.3060	-2.3331	-2.3079	0.2303	1.1289	0.606	0.9387
0.9970	0.8107	0.3978	0.2031	0.0839	0.0436	0.0117	-0.0117	-0.0201	-0.0420	0.03261	0.0026
										1715.8	9.68
-0.1892	-0.2230	-0.3068	-0.3886	-0.5642	-0.7159	-0.9443	-1.1932	-1.4267	-1.4727	241	
-1.5512	-1.6463	-1.7847	-2.2671	-2.6063	-2.3245	-2.4716	-2.4863	0.1398	1.1386	0.601	0.9820
1.0176	0.8404	0.4261	0.2131	0.0938	0.0436	0.0117	-0.0117	-0.0201	-0.0420	0.03493	-0.0147
										1689.6	10.63
-0.2864	-0.3000	-0.4330	-0.4892	-0.5459	-0.6529	-0.7834	-1.0466	-1.3018	-1.3944	248	
-1.5103	-1.6961	-2.0594	-2.7410	-2.8073	-2.6843	-2.4444	-2.5859	0.0324	1.1455	0.601	1.6090
1.0463	0.8847	0.4739	0.2506	0.1210	0.0949	0.0034	-0.0350	-0.0363	-0.0472	0.03765	-0.0170
										1689.5	11.74
-0.4212	-0.4305	-0.3644	-0.3306	-0.3783	-0.7388	-0.6389	-1.0132	-1.1030	-1.2221	254	
-1.4275	-1.6830	-1.9988	-2.3044	-2.8464	-2.8933	-2.8997	-2.6910	-0.0742	1.1479	0.395	0.9920
1.0501	0.8959	0.4799	0.2337	0.1033	0.0328	-0.0242	-0.0629	-0.1329	-0.3138	0.03949	-0.0340
										1668.5	12.70
-0.3785	-0.4944	-0.3791	-0.6030	-0.6693	-0.7917	-0.8418	-1.0440	-1.1391	-1.2463	260	
-1.5989	-1.7631	-1.9342	-2.2471	-2.8434	-2.8227	-2.7723	-2.5012	-0.1590	1.1443	0.395	1.0459
1.0645	0.9282	0.3237	0.2904	0.1383	0.0622	-0.0669	-0.0674	-0.1210	-0.2109	0.04232	-0.0466
										1668.5	13.72
-0.5402	-0.6507	-0.5910	-0.6682	-0.6349	-0.7822	-0.7857	-0.8910	-1.1909	-1.1347	266	
-1.2014	-1.4767	-1.6063	-1.8433	-2.2344	-2.6043	-2.8710	-2.4063	-0.2378	1.1610	0.590	1.0192
1.0979	0.9734	0.3682	0.3227	0.1649	0.0772	-0.0018	-0.0754	-0.1368	-0.2420	0.04464	-0.0729
										1642.1	14.80

Table 3.13

ARA RUN 230		AGARD CASE 8 - RAMP									
M=0.56	R=4.5*10 ⁶	&c/v=0.01492 Rad									
0.1932	0.0446	-0.0710	-0.1486	-0.2246	-0.2773	-0.3765	-0.4724	-0.5351	-0.5285	64	
-0.5814	-0.5533	-0.5533	-0.4691	-0.3353	-0.1156	0.0826	0.2940	1.1099	0.1090	0.013	0.0250
-0.1470	-0.3122	-0.5170	-0.4905	-0.4113	-0.2973	-0.2246	-0.1486	-0.0428	0.0380	0.00000	0.0014
										1743.7	0.01
0.1896	0.0316	-0.0931	-0.1829	-0.2611	-0.3476	-0.4390	-0.5504	-0.6336	-0.6452	74	
-0.7018	-0.6668	-0.6885	-0.6253	-0.5105	-0.3226	-0.1231	0.0815	1.1125	0.2877	0.610	0.1305
0.0216	-0.1680	-0.4157	-0.4174	-0.3492	-0.2627	-0.1979	-0.1280	-0.0532	0.0349	0.00388	-0.0009
										1731.9	1.08
0.1805	0.0248	-0.1076	-0.1987	-0.2848	-0.3776	-0.4769	-0.6061	-0.7088	-0.7336	77	
-0.8065	-0.7767	-0.8131	-0.7717	-0.6806	-0.5084	-0.3213	-0.0927	1.1045	0.4372	0.612	0.2184
0.1755	-0.0397	-0.3179	-0.3428	-0.2997	-0.2236	-0.1722	-0.1093	-0.0431	0.0348	0.00505	-0.0013
										1739.1	1.90
0.1832	0.0266	-0.1132	-0.2148	-0.3147	-0.4196	-0.5345	-0.6894	-0.8293	-0.8859	80	
-0.9758	-0.9609	-1.0208	-1.0058	-0.9625	-0.7977	-0.6228	-0.4163	1.0924	0.6328	0.610	0.3458
0.3747	0.1365	-0.1865	-0.2498	-0.2331	-0.1732	-0.1349	-0.0799	-0.0200	0.0466	0.00621	-0.0006
										1729.5	2.96
0.1850	0.0330	-0.1140	-0.2213	-0.3270	-0.4393	-0.5731	-0.7333	-0.9017	-0.9827	82	
-1.0884	-1.0884	-1.1776	-1.1825	-1.1776	-1.0223	-0.8621	-0.6639	1.0553	0.7481	0.613	0.4342
0.5054	0.2626	-0.0941	-0.1767	-0.1784	-0.1321	-0.0974	-0.0545	-0.0050	0.0562	0.00699	0.0005
										1743.8	1.83
0.1794	0.0266	-0.1229	-0.2391	-0.3504	-0.4716	-0.6161	-0.8021	-1.0064	-1.1127	84	
-1.2422	-1.2638	-1.4097	-1.4548	-1.4797	-1.2704	-1.1127	-0.9383	1.0230	0.8602	0.611	0.5422
0.6277	0.3853	0.0017	-0.0996	-0.1529	-0.0913	-0.0681	-0.0332	0.0083	0.0648	0.00776	0.0011
										1734.2	4.70
0.1730	0.0266	-0.1281	-0.2478	-0.3675	-0.5006	-0.6569	-0.8581	-1.0727	-1.2124	86	
-1.4618	-1.6348	-1.7213	-1.8510	-1.7346	-1.5417	-1.3604	-1.1874	0.9782	0.9548	0.611	0.6542
0.7434	0.5106	0.1081	-0.0233	-0.0565	-0.0466	-0.0333	-0.0083	0.0247	0.0682	0.00854	0.0049
										1731.7	3.67
0.1671	0.0278	-0.1245	-0.2474	-0.3702	-0.5029	-0.6618	-0.8470	-1.1746	-1.6873	88	
-2.0281	-1.9380	-2.0232	-1.9182	-1.7512	-1.9514	-1.5826	0.9092	1.0072	0.616	0.7628	
0.8198	0.6094	0.1933	0.0475	-0.0033	-0.0016	0.0033	0.0213	0.0426	0.0734	0.00731	0.0104
										1738.0	4.60
0.1613	0.0300	-0.1314	-0.2561	-0.3825	-0.5122	-0.6569	-0.9446	-1.5702	-2.3116	90	
-2.3056	-2.2234	-2.2384	-2.2484	-2.1986	-1.9823	-1.7777	-1.5842	0.3498	1.0776	0.611	0.9006
0.9063	0.7068	0.2887	0.1214	0.0499	0.0382	0.0383	0.0398	0.0365	0.0815	0.01009	0.0155
										1731.8	7.97
0.1478	0.0183	-0.1279	-0.2408	-0.3504	-0.5213	-0.7552	-1.4116	-1.6740	-2.1703	92	
-2.4246	-2.4030	-2.4014	-2.4279	-2.3316	-2.1722	-1.8513	-1.8547	0.7005	1.1143	0.611	1.0039
0.9715	0.7808	0.3620	0.1877	0.1030	0.0830	0.0681	0.0664	0.0731	0.0680	0.01086	0.0136
										1734.2	8.93
0.0743	-0.0000	-0.1603	-0.3280	-0.5631	-0.9049	-1.2314	-1.4366	-1.3206	-1.3793	94	
-1.7240	-2.2399	-2.3993	-2.5678	-2.4968	-2.3518	-2.1560	-2.1430	0.6992	1.1293	0.612	1.1209
1.0089	0.8356	0.4310	0.2444	0.1430	0.1132	0.0889	0.0710	0.0760	0.0710	0.01164	-0.0192
										1744.1	9.25
-0.0764	-0.2198	-0.4196	-0.3346	-0.5709	-1.0187	-1.2105	-1.3420	-1.3437	-1.2954	96	
-1.3570	-1.3435	-1.6933	-2.0046	-2.0195	-2.0208	-2.3610	-2.3993	0.6260	1.1472	0.609	1.1567
1.0306	0.8924	0.4912	0.3947	0.1818	0.1389	0.0932	0.0649	0.0516	0.0117	0.01241	-0.0758
										1729.7	10.56
-0.3721	-0.2038	-0.3272	-0.4160	-0.5576	-0.9414	-1.1136	-1.2688	-1.5827	-1.6743	98	
-1.7013	-1.6228	-1.6211	-1.5312	-1.8482	-2.5529	-3.0110	-2.3143	0.5476	1.1637	0.608	1.0703
1.0802	0.9333	0.9309	0.3172	0.1853	0.1219	0.0668	0.0317	-0.0100	-0.0902	0.01319	-0.0403
										1725.0	11.63
-0.3447	-0.3117	-0.4410	-0.6291	-0.7605	-0.8435	-0.8602	-1.3086	-1.3637	-1.3770	100	
-1.8803	-1.8820	-1.5783	-1.5537	-1.6454	-2.7373	-3.6056	-2.6073	0.4668	1.1436	0.608	1.1159
1.0714	0.9385	0.5418	0.3217	0.1834	0.1167	0.0617	0.0133	-0.0300	-0.1030	0.01398	-0.0399
										1727.6	12.69
-0.3488	-0.3242	-0.7003	-0.6889	-0.7121	-0.7643	-0.8249	-1.0185	-1.4478	-1.4919	102	
-1.5235	-1.5203	-1.4111	-1.5973	-1.6582	-2.7541	-2.7070	-2.7121	0.4040	1.1717	0.603	1.1387
1.1111	0.9831	0.5926	0.3626	0.2172	0.1348	0.0758	0.0133	-0.0430	-0.1566	0.01574	-0.0917
										1710.8	13.77
-0.4878	-0.3932	-0.6578	-0.5763	-0.7071	-0.7581	-0.8703	-0.9693	-1.1524	-1.2391	104	
-1.3972	-1.6704	-1.6760	-1.6390	-1.6947	-2.5837	-2.6380	-2.7978	0.3230	1.1711	0.602	1.0878
1.1235	1.0063	0.6136	0.3773	0.2227	0.1343	0.0544	-0.0204	-0.0554	-0.3139	0.01552	-0.0773
										1694.3	14.97

Table 3-14

ARA RUN 6 QUASI-STATIC M=0.3 R=2 6*10 ⁶ $\omega_m^2 = 10.75$ $\omega_0^2 = 11.16$ 1.8 Hz													
0.1349	-0.0066	-0.1537	-0.1877	-0.2443	-0.3405	-0.3801	-0.4424	-0.4594	-0.4707	80			
-0.4933	-0.5046	-0.4877	-0.4367	-0.3179	-0.1764	0.0160	0.2254	1.0008	-0.0292	0.299	0.0140		
-0.2783	-0.3858	-0.5103	-0.4480	-0.3914	-0.3065	-0.2900	-0.1764	-0.1198	-0.0292	0.00000	-0.0013	308.9	-0.12
0.1233	-0.0306	-0.1962	-0.2317	-0.2908	-0.3973	-0.4467	-0.5275	-0.5571	-0.5926	84			
-0.6221	-0.6517	-0.6376	-0.6340	-0.5334	-0.4328	-0.2954	-0.0483	1.0461	0.2002	0.293	0.1125		
-0.0779	-0.2435	-0.4328	-0.4032	-0.3559	-0.2968	-0.2554	-0.1784	-0.1252	-0.0424	0.01110	-0.0012	486.8	0.69
0.1092	-0.0412	-0.2031	-0.2610	-0.3304	-0.4460	-0.5097	-0.6138	-0.6716	-0.7121	88			
-0.7699	-0.8335	-0.8740	-0.9029	-0.8798	-0.8220	-0.6947	-0.4981	0.9247	0.4851	0.296	0.2514		
0.1901	-0.0007	-0.2641	-0.3015	-0.2899	-0.2436	-0.2147	-0.1569	-0.1164	-0.0470	0.02220	0.0016	498.0	2.04
0.1232	-0.0344	-0.1976	-0.2595	-0.3270	-0.4564	-0.5127	-0.6365	-0.7153	-0.7547	90			
-0.8371	-0.9179	-0.9686	-1.0361	-1.0473	-1.0473	-0.9573	-0.7941	0.7929	0.6128	0.300	0.3288		
0.3258	0.1232	-0.1807	-0.2201	-0.2370	-0.2088	-0.1694	-0.1073	-0.0794	-0.0287	0.02775	0.0010	311.8	2.84
0.1259	-0.0331	-0.2077	-0.2824	-0.3515	-0.4952	-0.5758	-0.7023	-0.7943	-0.8806	92			
-0.9438	-1.0704	-1.1624	-1.2602	-1.3292	-1.3694	-1.3464	-1.2026	0.6435	0.7643	0.297	0.4340		
0.4767	0.2582	-0.0869	-0.1617	-0.1904	-0.1302	-0.1387	-0.0984	-0.0696	-0.0179	0.03330	0.0011	500.8	3.63
0.0977	-0.0585	-0.2377	-0.3245	-0.3497	-0.5365	-0.6368	-0.7756	-0.9028	-0.9895	94			
-1.0763	-1.1972	-1.3654	-1.4985	-1.6488	-1.7413	-1.7934	-1.6719	0.3348	0.8668	0.296	0.5268		
0.4066	0.3753	-0.0064	-0.1163	-0.1426	-0.1510	-0.1452	-0.1047	-0.0758	-0.0353	0.03885	0.0034	498.0	4.62
0.1025	-0.0405	-0.2344	-0.3093	-0.4065	-0.5582	-0.6639	-0.8210	-0.9784	-1.0814	96			
-1.1957	-1.3158	-1.4417	-1.7705	-1.9507	-2.1222	-2.2338	-2.1851	-0.0062	0.9546	0.298	0.6326		
0.7259	0.5085	0.1025	-0.0119	-0.0977	-0.0862	-0.0376	-0.0405	-0.0119	0.04441	0.0040	503.6	5.61	
0.0881	-0.0716	-0.2609	-0.3614	-0.4619	-0.6334	-0.7376	-0.9410	-1.1361	-1.2663	98			
-1.3964	-1.5560	-1.7912	-1.9878	-2.4491	-2.6975	-2.9518	-2.7577	-0.5388	1.0284	0.293	0.7749		
0.8392	0.6381	0.1886	0.0526	-0.0420	-0.0590	-0.0775	-0.0539	-0.0339	-0.0243	0.04995	0.0051	487.0	6.39
0.1055	-0.0339	-0.2501	-0.3512	-0.4702	-0.6545	-0.7794	-0.9934	-1.2254	-1.3740	100			
-1.5346	-1.7427	-1.9865	-2.2957	-2.7833	-3.2412	-3.2861	-3.4634	-1.1243	1.0878	0.292	0.8889		
0.9273	0.7548	0.3029	0.1364	-0.0234	-0.0063	-0.0301	-0.0063	-0.0123	0.0056	0.09851	0.0072	484.3	7.67
0.0820	-0.0550	-0.2707	-0.3766	-0.5000	-0.6764	-0.8293	-1.0327	-1.3231	-1.4936	102			
-1.6758	-1.9051	-2.1932	-2.3871	-3.0692	-3.8217	-4.2391	-4.4155	-1.7523	1.0462	0.294	0.9937		
0.9580	0.8169	0.3877	0.1696	0.0702	0.0350	0.0096	0.0056	-0.0052	0.0056	0.06106	0.0075	489.9	9.72
0.0899	-0.0394	-0.2307	-0.3488	-0.4613	-0.6525	-0.8100	-1.0519	-1.3388	-1.5108	104			
-1.7269	-1.9607	-2.2037	-2.7450	-3.3131	-3.8924	-4.7759	-5.0912	-2.4019	0.9043	0.301	1.0301		
0.9337	0.8949	0.4612	0.2643	0.1237	0.0787	0.0306	0.0449	0.0281	0.0223	0.06662	0.0124	512.0	9.79
0.0302	-0.0381	-0.2441	-0.3719	-0.5086	-0.7040	-0.8892	-1.1449	-1.4878	-1.6971	106			
-1.4293	-2.2143	-2.5781	-3.1342	-3.9391	-4.4984	-5.7771	-6.2362	-3.2721	0.9474	0.296	1.1814		
0.9340	0.9398	0.3464	0.3313	0.1860	0.1231	0.0872	0.0840	0.0349	0.0179	0.07816	0.0140	493.5	10.83
0.0824	-0.0450	-0.2147	-0.3391	-0.4804	-0.6896	-0.8818	-1.1332	-1.5151	-1.7469	108			
-1.4937	-2.3123	-2.7138	-3.3188	-4.1330	-4.8680	-6.6680	-7.3443	-3.7011	0.8709	0.300	1.3470		
0.9301	0.9614	0.6108	0.4016	0.2433	0.1759	0.1246	0.1076	0.0737	0.0398	0.07772	0.0193	509.4	11.93
-0.0300	-0.1412	-0.2600	-0.3505	-0.4918	-0.7180	-0.9216	-1.3389	-1.6116	-1.8773	111			
-2.1406	-2.3048	-2.4972	-3.6357	-4.3404	-5.3094	-6.4364	-7.1262	-4.9871	0.6673	0.303	1.3407		
0.8534	0.9537	0.6617	0.4458	0.2659	0.1811	0.1302	0.0962	0.0367	0.0001	0.03603	0.0314	509.3	13.54
-0.0764	-0.2386	-0.4114	-0.4466	-0.4819	-0.7523	-0.9932	-1.3694	-1.7064	-1.9101	113			
-2.1617	-2.8037	-2.9449	-3.4097	-4.4903	-5.2073	-6.9411	-8.1377	-5.3660	0.6877	0.294	1.4063		
0.8934	1.0128	0.3053	0.4761	0.2880	0.1940	0.1293	0.0941	0.0394	-0.0411	0.09159	0.0008	490.0	14.55
-0.2376	-0.3739	-0.6077	-0.6356	-0.9934	-1.2393	-1.5836	-1.8271	-1.3392	-1.5836	115			
-1.3212	-1.6070	-1.8349	-2.3726	-3.1957	-3.7810	-4.3620	-5.1427	-4.8271	0.7340	0.295	1.3783		
0.4339	0.4936	0.3897	0.4501	0.2973	0.1694	0.0878	0.0469	-0.0408	-0.1104	0.69714	-0.0991	492.0	15.55

Table 3.15

ARA RUN 11 QUASI-STATIC													
M=0.58 R=4.6*10 ⁶ $\alpha_m=8.99$ $\alpha_0=9.55$ 1.8 Hz													
0.1774	0.0287	-0.0935	-0.1643	-0.2298	-0.3183	-0.3892	-0.4741	-0.5237	-0.5467	82			
-0.5680	-0.5680	-0.5503	-0.4741	-0.3396	-0.1448	0.0960	0.2872	1.0981	0.0730	0.585	0.0255		
-0.1643	-0.3431	-0.5220	-0.4812	-0.4069	-0.3113	-0.2387	-0.1590	-0.0811	0.0198	0.00000	0.0009		
										1626.6	-0.13		
0.1730	0.0196	-0.1055	-0.1795	-0.2500	-0.3364	-0.4175	-0.5127	-0.5743	-0.6078	84			
-0.6413	-0.6396	-0.6308	-0.5743	-0.4545	-0.2589	-0.0156	0.1677	1.0860	0.1747	0.585	0.0747		
-0.0632	-0.2589	-0.4686	-0.4510	-0.3910	-0.3012	-0.2342	-0.1637	-0.0826	0.0179	0.00537	0.0019		
										1634.0	0.26		
0.1804	0.0301	-0.1027	-0.1778	-0.2494	-0.3455	-0.4311	-0.5307	-0.6093	-0.6425	86			
-0.6932	-0.7054	-0.7106	-0.6687	-0.5691	-0.3927	-0.1481	0.0458	1.0836	0.3009	0.589	0.1350		
0.0686	-0.1463	-0.3892	-0.3962	-0.3420	-0.2651	-0.2005	-0.1324	-0.0625	0.0336	0.01074	0.0014		
										1648.5	0.76		
0.1733	0.0197	-0.1162	-0.2009	-0.2751	-0.3757	-0.4745	-0.5840	-0.6881	-0.7340	88			
-0.7905	-0.8188	-0.8382	-0.8188	-0.7464	-0.5822	-0.3474	-0.1391	1.0665	0.4169	0.585	0.2044		
0.1804	-0.0509	-0.3157	-0.3580	-0.3174	-0.2486	-0.1921	-0.1303	-0.0615	0.0215	0.01611	0.0036		
										1631.5	1.34		
0.1814	0.0268	-0.1121	-0.2017	-0.2843	-0.3915	-0.4969	-0.6252	-0.7553	-0.8063	90			
-0.8941	-0.9398	-0.9838	-0.9873	-0.9521	-0.9045	-0.5795	-0.3827	1.0285	0.5523	0.587	0.2881		
0.3238	0.0830	-0.2193	-0.2878	-0.2614	-0.2052	-0.1613	-0.1068	-0.0435	0.0356	0.02148	0.0053		
										1638.7	2.00		
0.1740	0.0196	-0.1243	-0.2173	-0.3085	-0.4244	-0.5384	-0.6841	-0.8332	-0.8873	92			
-1.0140	-1.0894	-1.1631	-1.2017	-1.2070	-1.0578	-0.8332	-0.6349	0.9338	0.6776	0.587	0.3753		
0.4460	0.1933	-0.1383	-0.2313	-0.2243	-0.1769	-0.1401	-0.0927	-0.0366	0.0371	0.02685	0.0063		
										1641.3	2.71		
0.1710	0.0197	-0.1317	-0.2285	-0.3271	-0.4503	-0.5787	-0.7495	-0.9219	-0.9976	94			
1.1085	-1.2634	-1.3813	-1.4622	-1.5291	-1.3707	-1.1472	-0.9290	0.8169	0.7976	0.586	0.4725		
0.5740	0.3206	-0.0419	-0.1599	-0.1739	-0.1440	-0.1141	-0.0784	-0.0243	0.0373	0.03222	0.0096		
										1636.4	3.49		
0.1712	0.0179	-0.1354	-0.2394	-0.3470	-0.4809	-0.6184	-0.8088	-1.0132	-1.1137	96			
-1.2424	-1.2335	-1.7077	-1.8875	-1.9227	-1.6900	-1.4715	-1.2706	0.6683	0.8904	0.585	0.5795		
0.6806	0.4374	0.0461	-0.0720	-0.1178	-0.0767	-0.0808	-0.0508	-0.0068	0.0461	0.03759	0.0113		
										1634.0	4.32		
0.1583	0.0214	-0.1313	-0.2418	-0.3559	-0.4998	-0.6402	-0.8420	-1.0543	-1.1227	98			
-1.1227	-2.1019	-2.2195	-2.2405	-2.1616	-1.9878	-1.7457	-1.5246	0.5005	0.7385	0.587	0.6808		
0.7725	0.5391	0.1320	-0.0014	-0.0628	-0.0593	-0.0505	-0.0277	0.0056	0.1512	0.04296	0.0176		
										1641.2	5.21		
0.1502	0.0145	-0.1453	-0.2559	-0.3715	-0.5226	-0.6791	-0.8713	-1.0010	-1.1398	100			
-2.3847	-2.5110	-2.5626	-2.5128	-2.4541	-2.2673	-2.0415	-1.7925	0.3328	1.0264	0.583	0.7996		
0.8593	0.6316	0.2137	0.0554	-0.0175	-0.0264	-0.0264	-0.0104	0.0145	0.0483	0.04832	0.0252		
										1619.3	6.10		
0.1342	0.0091	-0.1427	-0.2517	-0.3804	-0.5286	-0.6733	-0.8520	-1.1450	-1.9739	102			
-2.6742	-2.7457	-2.7743	-2.7350	-2.6707	-2.4956	-2.2223	-2.0865	0.1520	1.0739	0.581	0.9017		
0.9345	0.7184	0.2932	0.1199	0.0288	0.0073	0.0034	0.0037	0.0198	0.0466	0.05371	0.0327		
										1612.1	7.01		
0.0962	-0.0123	-0.1475	-0.2613	-0.3787	-0.5191	-0.6650	-0.8517	-1.3763	-1.9630	104			
-2.7262	-2.7884	-2.8898	-2.8489	-2.7848	-2.6195	-2.3989	-2.3474	0.0339	1.0779	0.582	0.9428		
0.7352	0.7506	0.3363	0.1389	0.0499	0.0233	0.0037	0.0019	0.0108	0.0250	0.05908	0.0369		
										1619.4	7.94		
0.0393	-0.0499	-0.1765	-0.2782	-0.3870	-0.5350	-0.6760	-0.9221	-1.4465	-1.8514	106			
-2.1866	-2.8343	-2.9092	-2.9377	-2.8878	-2.7255	-2.5221	-2.4829	0.0659	1.0899	0.581	0.9565		
0.9811	0.7849	0.3693	0.1660	0.0607	0.0250	-0.0017	-0.0124	-0.0106	-0.0088	0.06445	0.0353		
										1614.6	8.79		
-0.1962	-0.2046	-0.2638	-0.3051	-0.3895	-0.5474	-0.7179	-1.0157	-1.5344	-1.8448	108			
-1.9381	-2.0907	-2.3890	-2.7833	-2.9430	-2.8390	-2.6649	-2.6416	-2.1544	1.0928	0.579	0.9632		
0.9959	0.8057	0.3911	0.1812	0.0681	0.0287	-0.0090	-0.0306	-0.0431	-0.0665	0.06982	0.0150		
										1604.9	9.74		
-0.2378	-0.2612	-0.3242	-0.3476	-0.4322	-0.5870	-0.7868	-1.0477	-1.5463	-1.6867	110			
-1.7983	-1.8971	-1.9729	-1.9837	-2.2013	-2.8764	-2.7720	-2.7648	-2.396	1.0995	0.577	0.9387		
1.0059	0.3245	0.4138	0.1942	0.0682	0.0214	-0.0200	-0.0524	-0.0776	-0.1154	0.07520	0.0001		
										1600.1	10.63		
-0.3974	-0.4787	-0.5509	-0.5491	-0.5906	-0.6646	-0.8307	-1.0275	-1.2406	-1.2333	112			
-1.1357	-1.1358	-1.0943	-1.1792	-2.5892	-2.6686	-2.7715	-2.7625	-0.1754	1.1064	0.576	0.9087		
1.0144	0.8447	0.4330	0.2110	0.0792	0.0160	-0.0364	-0.0797	-0.1176	-0.1916	0.08057	-0.0508		
										1599.2	11.56		

Table 3.16

ARA RUN 151 QUASI-STATIC
 $M=0.745$ $R=5.5 \times 10^6$ $\alpha_m=0.09$ $\alpha_o=5.$ 1.8 Hz

0.1715	0.0418	-0.0567	-0.1228	-0.1689	-0.2313	-0.2799	-0.3223	-0.2811	-0.2599	15
-0.2151	-0.1427	-0.0604	0.0904	0.2949	0.5019	0.7239	0.8623	0.9994	-0.4644	0.746
-0.7250	-0.8061	-1.1777	-1.2787	-1.3560	-0.6964	-0.4146	-0.1689	-0.0592	0.0543	0.00000 2309.7 -3.27
0.1906	0.0482	-0.0605	-0.1305	-0.1830	-0.2529	-0.3079	-0.3566	-0.3266	-0.3154	16
-0.2654	-0.1980	-0.1180	0.0257	0.2331	0.4417	0.6741	0.8240	1.0327	-0.3866	0.745
-0.6477	-0.7514	-1.1313	-1.2425	-1.3187	-0.6340	-0.3179	-0.1642	-0.0743	0.0419	0.00555 2305.1 -2.85
0.1968	0.0519	-0.0593	-0.1342	-0.1942	-0.2692	-0.3329	-0.3916	-0.3716	-0.3629	17
-0.3167	-0.2492	-0.1717	-0.0268	0.1681	0.3843	0.6204	0.7766	1.0527	-0.3167	0.745
-0.5740	-0.6940	-1.0775	-1.1987	-1.2699	-0.5565	-0.2779	-0.1730	-0.0818	0.0407	0.01109 2305.1 -2.40
0.2022	0.0530	-0.0639	-0.1435	-0.2082	-0.2928	-0.3587	-0.4370	-0.4271	-0.4096	18
-0.3748	-0.3102	-0.2318	-0.0888	0.1089	0.3265	0.5665	0.7245	1.0801	-0.2306	0.747
-0.4867	-0.6310	-1.0003	-1.1421	-1.2117	-0.4159	-0.2729	-0.1871	-0.0913	0.0380	0.01663 2315.9 -1.98
0.2095	0.0542	-0.0688	-0.1521	-0.2254	-0.3111	-0.3906	-0.4851	-0.4925	-0.4764	19
-0.4315	-0.3844	-0.3136	-0.1682	0.0269	0.2592	0.5003	0.6680	1.1104	-0.1297	0.748
-0.3844	-0.5571	-0.9100	-1.0740	-1.0802	-0.3658	-0.2912	-0.1955	-0.0937	0.0356	0.02217 2317.8 -1.54
0.2145	0.0530	-0.0713	-0.1620	-0.2427	-0.3384	-0.4291	-0.5360	-0.5396	-0.5522	20
-0.5298	-0.4652	-0.3943	-0.2527	-0.0563	0.1698	0.4233	0.5998	1.1329	-0.0303	0.749
-0.2862	-0.4764	-0.8231	-0.9660	-0.9274	-0.3949	-0.3049	-0.1930	-0.0924	0.0406	0.02772 2317.6 -1.06
0.2026	0.0454	-0.0834	-0.1775	-0.2592	-0.3607	-0.4622	-0.6008	-0.6637	-0.6565	21
-0.6281	-0.5525	-0.4882	-0.3433	-0.1552	0.0726	0.3301	0.5009	1.1384	0.0590	0.750
-0.1911	-0.4003	-0.7556	-0.9152	-0.5166	-0.4077	-0.3012	-0.1960	-0.0933	0.0342	0.03327 2326.6 -0.59
0.2095	0.0512	-0.0788	-0.1745	-0.2616	-0.3708	-0.4873	-0.6112	-0.7965	-0.7811	22
-0.6971	-0.6296	-0.5695	-0.4272	-0.2444	-0.0187	0.2389	0.4192	1.1406	0.1678	0.755
-0.0764	-0.2972	-0.6701	-0.7167	-0.5437	-0.3855	-0.2874	-0.1831	-0.0825	0.0414	0.03881 2347.7 -0.06
0.2091	0.0474	-0.0836	-0.1840	-0.2721	-0.3738	-0.4582	-0.9492	-0.8806	-0.8182	23
-0.7558	-0.7178	-0.6517	-0.5097	-0.3334	-0.1105	0.1515	0.3413	1.1396	0.2593	0.755
0.0144	-0.2085	-0.5880	-0.6345	-0.5121	-0.3750	-0.2734	-0.1766	-0.0811	0.0401	0.04436 2352.2 0.40
0.2049	0.0427	-0.0876	-0.1884	-0.2695	-0.3580	-0.4759	-1.0449	-0.9565	-0.8926	24
-0.8594	-0.8151	-0.7303	-0.5951	-0.4219	-0.1970	0.0685	0.2583	1.1402	0.3401	0.754
0.0968	-0.1755	-0.5079	-0.5706	-0.4636	-0.3432	-0.2584	-0.1673	-0.0753	0.0415	0.04990 2343.4 0.86
0.2115	0.0527	-0.0803	-0.1727	-0.2441	-0.3377	-0.8894	-1.1135	-1.0187	-0.9731	25
-0.9363	-0.8820	-0.7958	-0.6632	-0.5089	-0.2774	-0.0101	0.1795	1.1486	0.4258	0.754
0.1894	-0.0458	-0.4202	-0.5019	-0.4214	-0.3118	-0.2355	-0.1505	-0.0668	0.0465	0.05545 2338.8 1.31
0.2011	0.0516	-0.0794	-0.1635	-0.2364	-0.4317	-1.2239	-1.1732	-1.1015	-1.0570	26
-1.0076	-0.9532	-0.8889	-0.7394	-0.6072	-0.3711	-0.1128	0.0812	1.1342	0.5002	0.752
0.2654	0.0244	-0.3489	-0.4403	-0.3785	-0.2908	-0.2216	-0.1449	-0.0646	0.0464	0.06098 2330.3 1.79
0.1928	0.0543	-0.0689	-0.1486	-0.2731	-0.5619	-1.3014	-1.2417	-1.1707	-1.1246	27
-1.0761	-1.0325	-0.9703	-0.8047	-0.7051	-0.4398	-0.2021	-0.0092	1.1200	0.3598	0.748
0.3257	0.0842	-0.2943	-0.3976	-0.3528	-0.2743	-0.2121	-0.1399	-0.0677	0.0406	0.06653 2313.3 2.21
0.1847	0.0675	-0.0484	-0.1360	-0.3568	-0.6307	-1.3276	-1.2647	-1.2018	-1.1488	28
-1.1155	-1.0760	-1.0032	-0.8404	-0.7762	-0.5160	-0.2705	-0.0853	1.1049	0.6189	0.752
0.3956	0.1591	-0.2224	-0.3322	-0.3050	-0.2446	-0.1878	-0.1200	-0.0521	0.0453	0.07203 2324.7 2.61
0.1596	0.0671	-0.0455	-0.2269	-0.4720	-0.6759	-1.3939	-1.3464	-1.2726	-1.2201	29
-1.1876	-1.1450	-1.0687	-0.9324	-0.8636	-0.5921	-0.3457	-0.1993	1.0890	0.6637	0.746
0.4461	0.1959	-0.1894	-0.3044	-0.2932	-0.2419	-0.1881	-0.1293	-0.0630	0.0258	0.07762 2302.4 2.95
0.1177	0.0543	-0.0764	-0.2544	-0.4860	-0.6814	-1.1096	-1.3797	-1.3025	-1.2751	30
-1.2191	-1.1755	-1.0996	-0.9863	-0.9092	-0.6304	-0.3889	-0.2047	1.0700	0.6978	0.747
0.4837	0.2385	-0.1524	-0.2768	-0.2756	-0.2271	-0.1822	-0.1287	-0.0702	0.0132	0.08317 2313.7 3.35

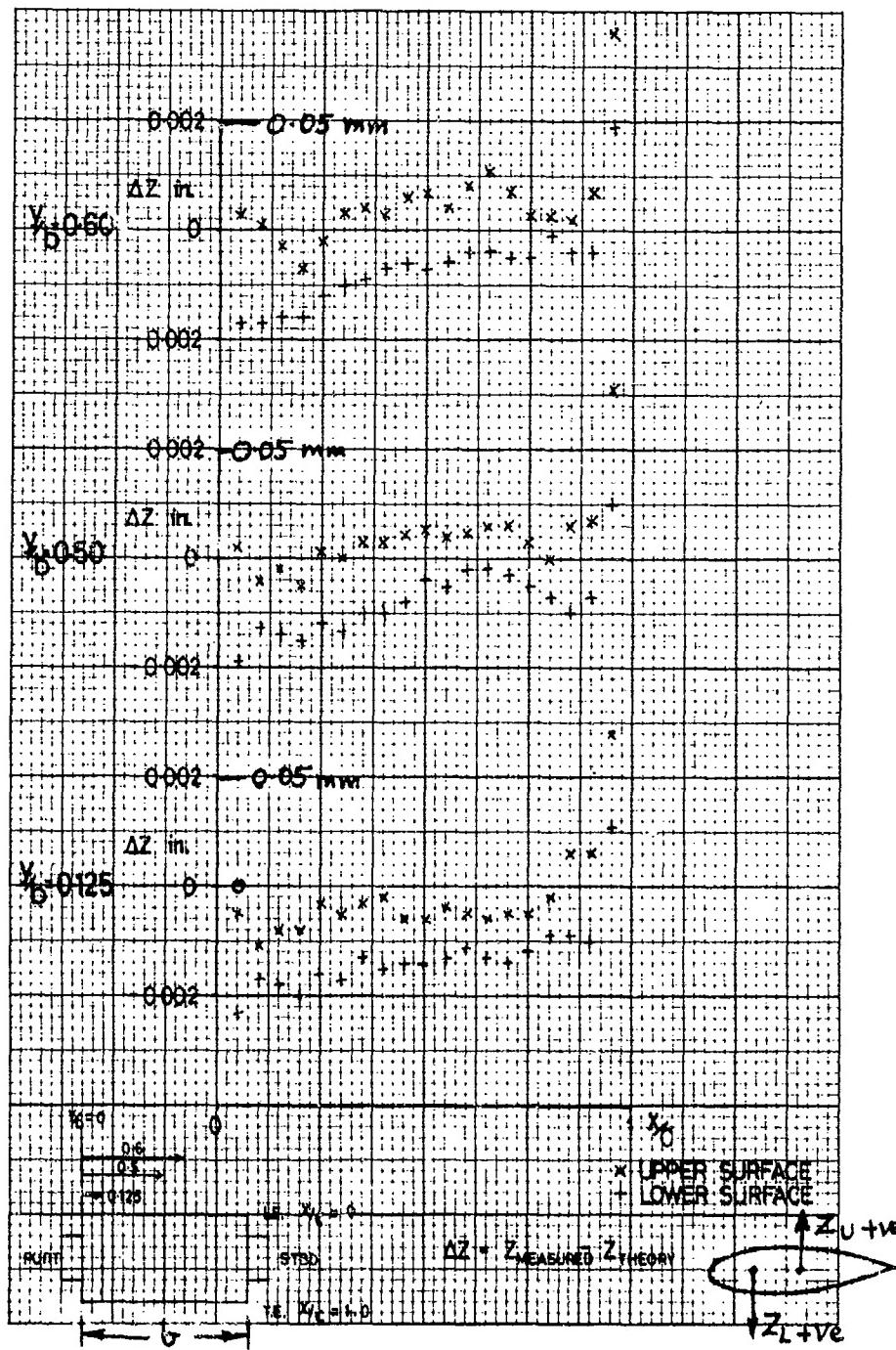


Fig 3.1 Profile inspection of NACA 0012 wing: $Z_m - Z_t$

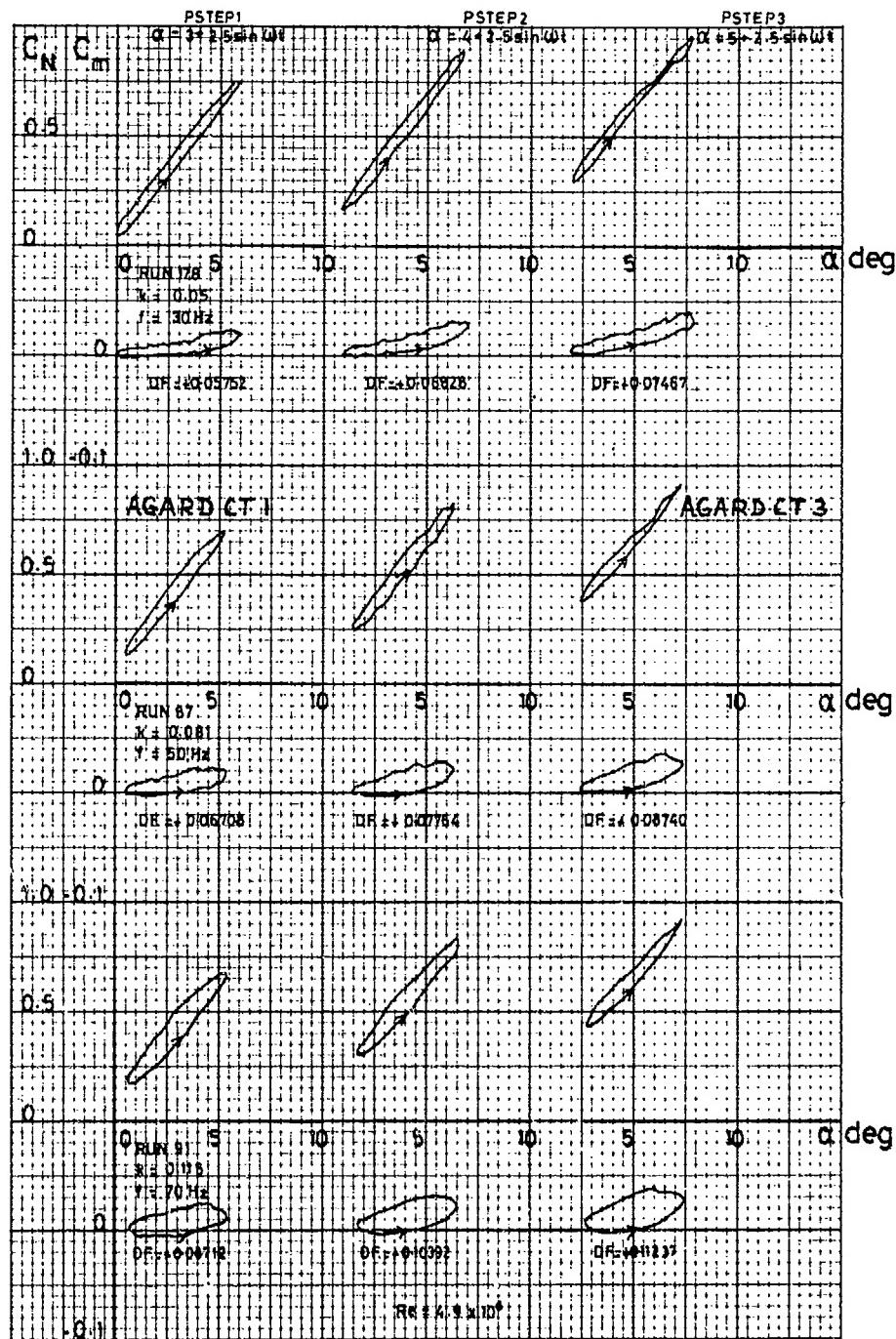


Fig 3.2 C_N, C_M v. incidence over range of $\alpha_m = 3^\circ, 4^\circ, 5^\circ$; $\alpha_0 = 2.5^\circ$.
Effect of frequency $k = 0.05, 0.08, 0.12$; $M = 0.6$

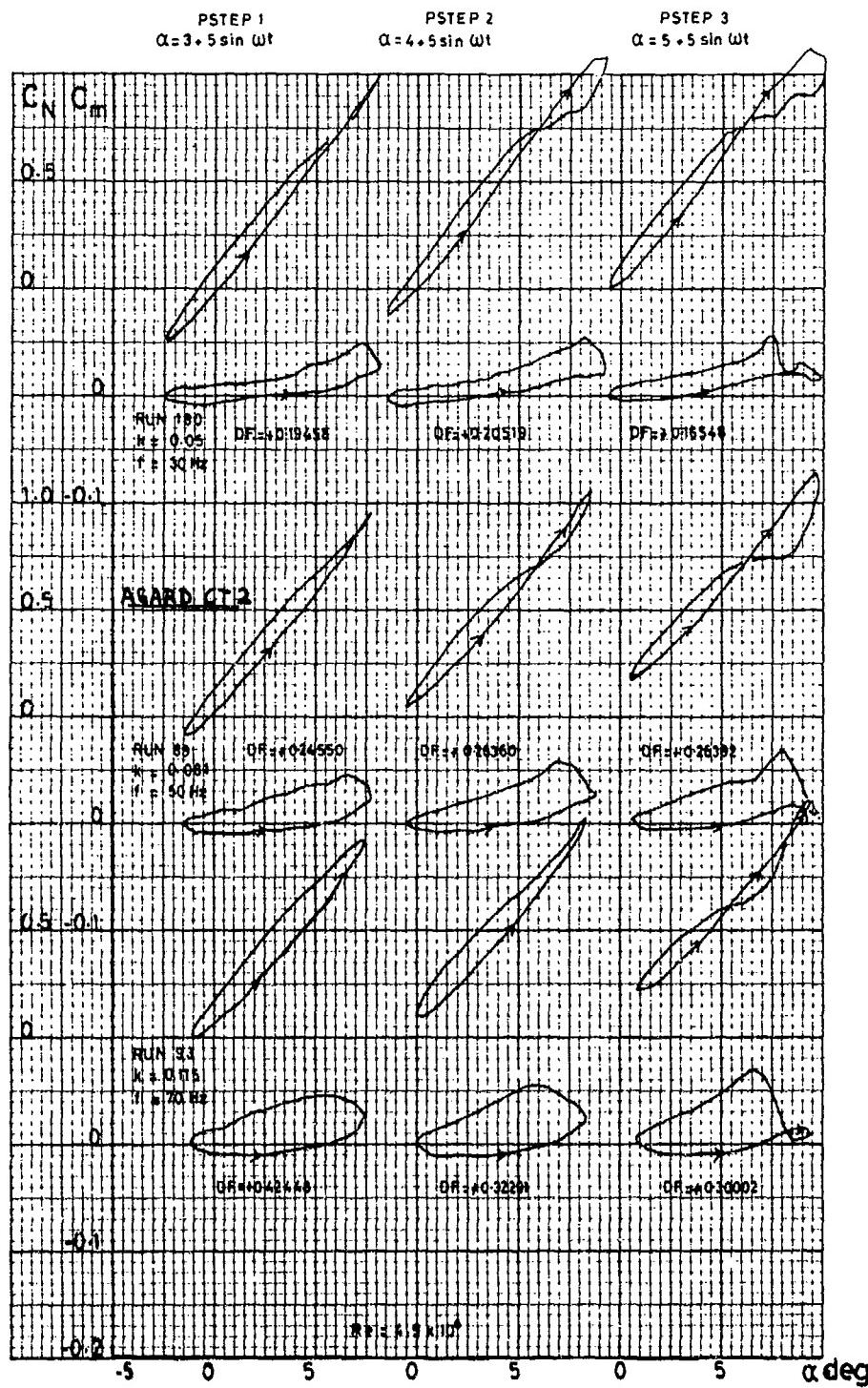
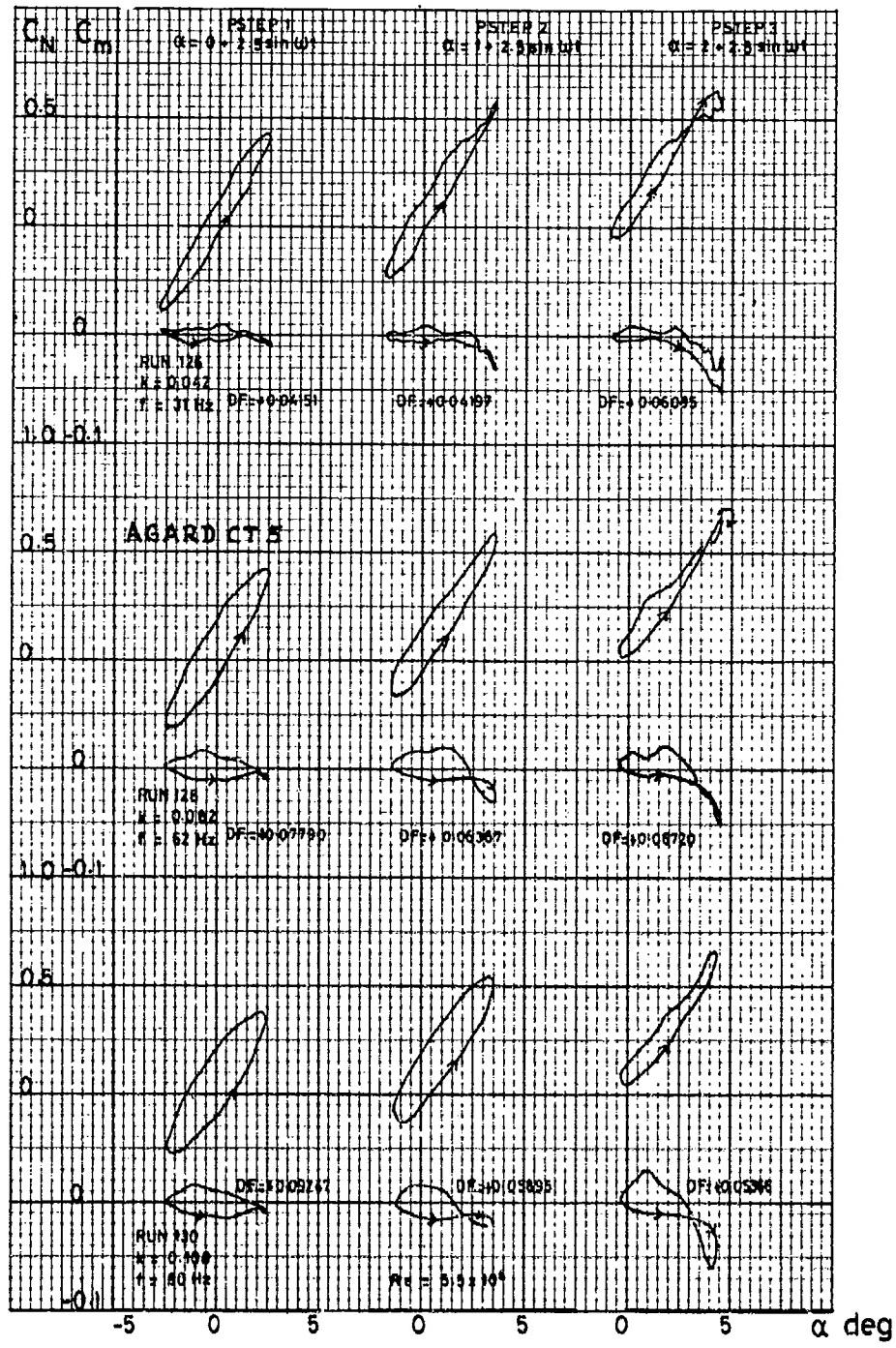


Fig 3.3 C_N , C_m v. incidence over range of $\alpha_m = 3^0, 4^0, 5^0$; $\alpha_0 = 5^0$.
Effect of frequency $k = 0.05, 0.08, 0.12$; $M = 0.6$.



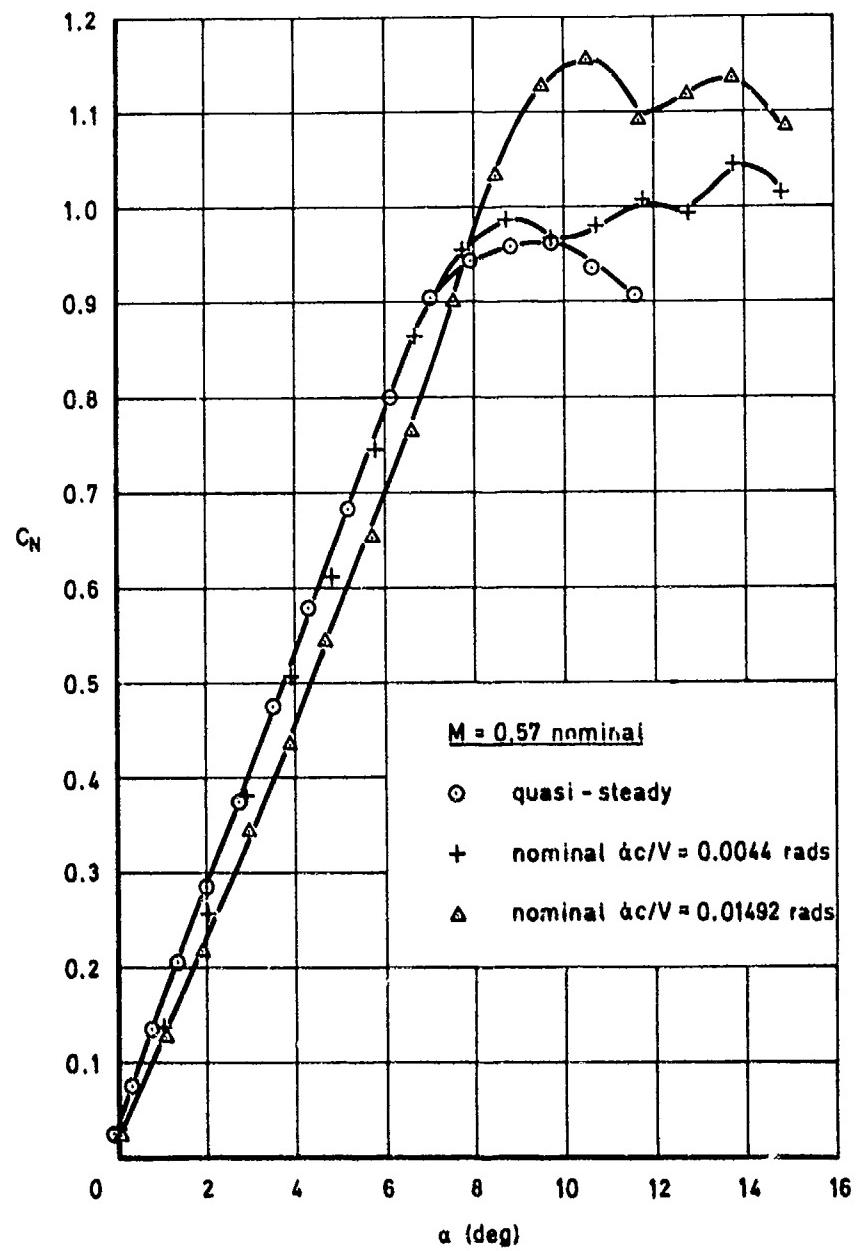


Fig 3.5 Lift v. incidence for different rates of change

DATA SET 4

NLR 7301 SUPERCRITICAL AIRFOIL OSCILLATORY PITCHING AND OSCILLATING FLAP

by

R.J. Zwaan, NLR

INTRODUCTION

The supercritical airfoil NLR 7301 has a maximum thickness of 16.5 per cent of the chord. In the set of two-dimensional aeroelastic configurations this airfoil represents the category of thick and blunt-nosed airfoils.

The airfoil was investigated in two wind-tunnel tests with different models. In the first test the model could be driven harmonically in a pitching motion about an axis at 40 per cent of the chord. Information about this configuration is designated with the letter "A". In the second test harmonic rotation of a trailing-edge flap was considered. The flap axis was located at 75 per cent of the chord; the flap had no aerodynamic balance. Information about this configuration is designated with the letter "B".

In transonic flow the contribution of the shock to the aerodynamic loading can of course be very different. As an illustration, pressure distributions on the upper surface are compared for a flow with a strong shock and a shock-free flow. Also results of thin-airfoil theory have been added. In the strong shock cases (A: Fig. 4.1, B: Fig. 4.5) the pressure peak due to the moving shock dominates in the pressure distribution, with a strength which diminishes with frequency. Although the flow conditions are the same for both configurations, the mean pressure distributions differ slightly. The cause of these differences could not be traced. In the shock-free cases (A: Fig. 4.2, B: Fig. 4.6) the pressure distribution shows a wide bulge. The pressure distributions of configuration A show very clearly that with increasing frequency the bulge decreases while at the same time a weak shock develops. Also here the mean pressure distributions should be the same. For unexplained reasons, however, shock-free flow could only be realized at slightly different Mach numbers.

Lift and moment coefficients are presented in figures 4.3 and 4.4 for configuration A and in figures 4.7 and 4.8 for configuration B. The influence of fixing boundary layer transition is remarkable. Configuration A shows only minor differences. Forced transition at 0.3 c is obviously not so effective in this case. The differences are larger for configuration B, which includes also fixed transition at 0.07 c. Characteristic changes occur in particular in the lift coefficient at low frequencies. Transition fixing has obviously the effect of reducing both the lift magnitude and the phase lag.

An aspect that emerges especially in the present case of a supercritical airfoil is the difference in the specification of theoretical and experimental shock-free flow. In the General Review it was pointed out that this difference is mainly due to viscous effects and tunnel interference. It was further proposed to choose the CT specification such that theory would produce a flow similar to that observed in the experiment. This is illustrated in figure 4.9 where the theoretical design pressure distribution calculated with a hodograph theory is compared with a shock-free pressure distribution measured at free transition.

1 AIRFOIL

1.1 Designation	NLR 7301 (also NLR HT 7310810)
1.2 Type of airfoil	Thick, aft-loaded, shock-free supercritical; designed by means of Boerstoel hodograph method
1.3 Geometry	See Table 4.1
Nose radius	0.05 c
Maximum thickness	t/c = 16.5 %
Base thickness	Zero
1.4 Design condition	Potential flow (hodograph theory): M = 0.721 C _q = 0.595
Design condition	Steady experiment (free transition, NLR Pilot Tunnel): M = 0.747, C _q = 0.455; see Fig. 4.9
1.5 Additional remarks	"Shock-free" pressure distributions for configuration A shown in Fig. 4.2 and for configuration B shown in Fig. 4.6
1.6 References on airfoil	

2 MODEL GEOMETRY

2.1 Chord length	0.18 m
2.2 Span	0.42 m
2.3 Actual model coordinates and accuracy of measurements	See Table 4.2
2.4 Flap: hinge and gap details	A: not applicable B: hinge axis at 0.75 c; gap width 0.35 mm

- 2.5 Additional remarks
2.6 References on model

3 WIND TUNNEL

- 3.1 Designation NLR Pilot Tunnel
3.2 Type of tunnel Continuous, closed circuit
3.3 Test section dimensions Rectangular; see Fig. 4.10
height 0.55 m, width 0.42 m
3.4 Type of roof and floor 10 % slotted top and bottom walls, separate top and bottom plenums
3.5 Type of side walls Solid side walls
3.6 Ventilation geometry See Fig. 4.10
3.7 Thickness of side wall boundary layer Thickness 10 % of test section semi-width, no special treatment
3.8 Thickness of boundary layers at roof and floor Not measured; probably comparable with side wall boundary layers
3.9 Method of measuring Mach number Derived from static pressure measured upstream of model and from total pressure measured in settling chamber
3.10 Uniformity of Mach number over test section See Fig. 4.11 (empty test section)
3.11 Sources and levels of noise or turbulence in empty tunnel Turbulence/noise level, see Fig. 4.12
3.12 Tunnel resonances No evidence
3.13 Additional remarks For two-dimensionality of the flow see Ref. 4.3
3.14 References on tunnel Ref. 4.2

4 MODEL MOTION

- 4.1 Mode of applied motion A: pitching oscillation of airfoil
B: oscillation of trailing-edge flap
4.2 Range of amplitude A: $\alpha_0 = 0.1^\circ$ to 1.5°
B: $\delta_0 = 0.1^\circ$ to 2.0°
4.3 Range of frequency A: f = 0 to 80 Hz; k = 0 to 0.26
B: f = 0 to 200 Hz; k = 0 to 0.65
4.4 Method of application A} hydraulic excitation at one side
B} of the model
4.5 Purity of applied motion Checked by spectral analysis; no data stored
4.6 Natural frequencies and normal modes of model No interference with natural vibration modes
4.7 Static or dynamic elastic distortion during tests Negligible
4.8 Additional remarks -

5 TEST CONDITIONS

- 5.1 Tunnel height/model chord ratio 3.1
5.2 Tunnel width/model chord ratio 2.3
5.3 Range of Mach number A: M = 0.5 to 0.8
B: M = 0.5 to 0.82
5.4 Range of tunnel total pressure Atmospheric
5.5 Range of tunnel total temperature 313 ± 1 K
5.6 Range of model steady mean incidence A: $\alpha_m = 0^\circ$ to 3°
B: $\alpha_m = 0^\circ$ to 3° ; $\delta_m = 0^\circ$
5.7 Definition of model incidence Incidence datum line $\alpha = 0$ relates to the x-axis as used in Tables 4.1 and 4.2. Datum line is parallel to test section centre line for $\alpha_m = 0$
5.8 Position of transition, if free A} part of the test performed with natural
B} transition; position of transition not measured
5.9 Position and type of trip, if transition fixed A: strip of carborundum grains at 0.3 c
B: strip of carborundum grains at 0.07 c or 0.3 c
5.10 For mixed flow, position of sonic boundary in relation to roof and floor Not measured
5.11 Flow instabilities during tests No evidence

5.12	Additional remarks	-	
5.13	References describing tests	A: Ref. 4.4 B: not available	
6	MEASUREMENTS AND OBSERVATIONS		
6.1	Steady pressures for the mean conditions		✓
6.2	Steady pressures for small changes from the mean conditions		✓
6.3	Quasi-steady pressures		
6.4	Unsteady pressures		✓
6.5	Steady forces for the mean conditions	measured directly integrated press.	
6.6	Steady forces for small changes from the mean conditions	measured directly integrated press.	
6.7	Quasi-steady forces	measured directly integrated press.	
6.8	Unsteady forces	measured directly integrated press.	
6.9	Measurement of actual motion at points on model		✓
6.10	Observation or measurement of boundary layer properties		
6.11	Visualization of surface flow		
6.12	Visualization of shockwave movements		
6.13	Additional remarks		

7 INSTRUMENTATION

7.1 Steady pressures	
7.1.1 Position of orifices spanwise and chordwise	See 7.2.1
7.1.2 Type of measuring system	See 7.2.3
7.2 Unsteady pressures	
7.2.1 Position of orifices spanwise and chordwise	A: see Figs 4.13 and 4.14 B: see Figs 4.15 and 4.16
7.2.2 Diameter of orifices	0.8 mm
7.2.3 Type of measuring system	A: 40 pressure tubes + 13 <i>in situ</i> pressure transducers B: 46 pressure tubes + 12 <i>in situ</i> pressure transducers
7.2.4 Type of transducers	±7.5 psi Statham differential pressure transducers, and ±5 psi Kulite miniature pressure transducers
7.2.5 Principle and accuracy of calibration	Calibration uses transfer functions of pressure tubes, see Ref. 4.4; for accuracy see 9.10
7.3 Model motion	
7.3.1 Method of measurement	A: with accelerometers, see Fig. 4.13 B: with accelerometers, see Fig. 4.15
7.3.2 Accuracy	See 9.10
7.4 Processing of unsteady measurements	
7.4.1 Method of acquiring and processing measurements	See Fig. 4.17
7.4.2 Type of analysis	A: signal analysis of TFA over 20 cycles for $f = 30, 80$ Hz and 60 cycles for $f = 200$ Hz B: signal length during TFA analysis was 1 s
7.4.3 Unsteady pressure quantities obtained and accuracies achieved	A: Fundamental harmonics B: Fundamental harmonics and occasionally second and third harmonics For accuracy see 9.10
7.4.4 Method of integration to obtain forces	Trapezoidal rule
7.5 Additional remarks	-
7.6 References on techniques	A: Refs 4.4, 4.5 B: Ref. 4.6

8 DATA PRESENTATION

8.1	Test cases for which data could be made available	A: see Table 4.3 B: not available
8.2	Test cases for which data are included in this document	A} : see Table 4.4 B}
8.3	Steady pressures	Mean pressures for: A: Tables 4.5 to 4.14 B: Tables 4.15 to 4.23
8.4	Quasi-steady or steady perturbation pressures	Steady pressure derivatives for: A: Tables 4.5, 4.8, 4.12 B: Tables 4.15, 4.17, 4.19
8.5	Unsteady pressures	A: Tables 4.6, 4.7, 4.9 to 4.11, 4.13, 4.14 B: Tables 4.16, 4.18, 4.20 to 4.23
8.6	Steady forces or moments	See 8.3
8.7	Quasi-steady or steady perturbation forces	See 8.4
8.8	Unsteady forces and moments	See 8.5
8.9	Other forms in which data could be made available if required	-
8.10	References giving other presentations of data	-

9 COMMENTS ON DATA

9.1 Accuracy

9.1.1	Mach number	±0.002. No corrections made for Mach number nonuniformity
9.1.2	Steady incidence	±0.02°
9.1.3	Reduced frequency	±0.0005
9.1.4	Steady pressure coefficients	Not known
9.1.5	Steady pressure derivatives	Not applicable
9.1.6	Unsteady pressure coefficients	Not known
9.2	Sensitivity to small changes of parameter	No evidence
9.3	Spanwise variations	No evidence
9.4	Non-linearities	Part of analysis of experimental results; see Ref. 4.4
9.5	Influence of tunnel total pressure	-
9.6	Wall interference corrections	No corrections included, but under steady conditions it is normal to make the following corrections to measurements made in this tunnel: steady corrections: $\Delta C_L = -1.4 C_L + 0.56 (C_a + 0.25 C_t) / \sqrt{1-N^2}$, (deg) (±15 %) $\Delta C_T = -0.015 C_t / (1-N^2)$, (±30 %) $\Delta C_M = -0.25 \Delta C_t$, (±30 %)
9.7	Other relevant tests on <u>same model</u>	-
9.8	Relevant tests on other models of nominally the <u>same</u> airfoil	See Data Set 5
9.9	Any remarks relevant to comparison between experiment and theory	-
9.10	Additional remarks	No systematic investigations of separate accuracies have been performed, accuracy of lift and moment coefficients is estimated to be 5 to 10 per cent in magnitude and 3 to 6 degrees in phase angle
9.11	References on discussion of data	A: Ref. 4.4

10 PERSONAL CONTACT FOR FURTHER INFORMATION

R.J. Zwaan, National Aerospace Laboratory (NLR), Anthony Fokkerweg 2, 1059 CH Amsterdam,
The Netherlands

11 LIST OF REFERENCES

- 4.1 J. Barche c.s. Experimental data base for computer program assessment AGARD-AR-138, 1979
- 4.2 J. Zwaaneveld Principal data of the NLL Pilot Tunnel NLL Report MP 185, 1959
- 4.3 H.A. Dambrink Investigation of the 2-dimensionality of the flow around a profile in the NLR 0.55x0.42 m² transonic wind tunnel NLR Memorandum AC-72-018, 1972
- 4.4 H. Tijdemann Investigations of the transonic flow around oscillating airfoils NLR TR 77090 U, 1977
- 4.5 P.H. Fuykschot L.J.M. Joosten DYDRA-Data logger for dynamic measurements NLR MP 69012 U, 1969
- 4.6 P.H. Fuykschot PHAROS, processor for harmonic analysis of the response of oscillating surfaces NLR MP 77012 U, 1977
- 4.7 S.R. Bland AGARD Two-dimensional aeroelastic configurations AGARD-AR-156, 1979

12 NOTATION AND LIST OF SYMBOLS

DATA SET	STANDARD
ALPHA	mean wing incidence, α_m , deg
AMPL.	flap amplitude, δ_0 , deg; see Note 2 below
C2	pitch amplitude, a_0 , deg; see Note 2 below
CL	mean wing lift coefficient, C_l
CLIM	k_a'' in Tables 4.5 to 4.14; k_c'' in Tables 4.15 to 4.23
CLRE	k_a' in Tables 4.5 to 4.4; k_c' in Tables 4.15 to 4.23
CM	mean wing moment coefficient (about 0.25 c), C_m
CMIN	m_a'' in Tables 4.5 to 4.14; m_c'' in Tables 4.15 to 4.23
CNRE	m_a' in Tables 4.5 to 4.14; m_c' in Tables 4.15 to 4.23
CP	mean pressure coefficient, C_p
CPIM	imaginary component of oscillatory pressure coefficient, rad ⁻¹ . In Tables 4.5 to 4.14 it represents C_p''/α_0 , in Tables 4.15 to 4.23 it represents C_p''/δ_0
CPRE	real component of oscillatory pressure coefficient, rad ⁻¹ . In Tables 4.5 to 4.14 it represents C_p'/α_0 , in Tables 4.15 to 4.23 it represents C_p'/δ_0 . If k = 0, then CPRE = $[C_p(+\delta_0) - C_p(-\delta_0)]/2\delta_0$ and CPIM = $[C_p(-\delta_0) - C_p(+\delta_0)]/2\delta_0$, resp.
DSLTA	mean flap angle, δ_g , deg
FREQ.	frequency, f, Hz
HARM	order of harmonic
k_a	oscillatory wing lift coefficient, \tilde{C}_l/α_0 , rad ⁻¹
k_c	oscillatory wing lift coefficient, \tilde{C}_l/δ_0 , rad ⁻¹
M	mean local Mach number, M_l
MACH	free-stream Mach number, M
a_a	oscillatory wing moment coefficient, $-2 \tilde{C}_m/\alpha_0$, rad ⁻¹
a_c	oscillatory wing moment coefficient, $-2 \tilde{C}_m/\delta_0$, rad ⁻¹
NETHURNR.	run number
NCHE, NCIN	real and imaginary components of oscillatory flap moment coefficient, $-2 \tilde{C}_h/\delta_0$, rad ⁻¹
P0	total pressure, p_t , Pa
Q	dynamic pressure, q, Pa
RCRE, RCIN	real and imaginary components of oscillatory flap lift coefficient, \tilde{C}_{lf}/δ_0 , rad ⁻¹
RE	Reynolds number based on wing chord, Re
RFREQ	reduced frequency, $k = \pi f c / V$
•	(suffix) upper side
-	(suffix) lower side
*	(superscript) critical value

Note 1: Symbols not mentioned here conform to the notation in the General Review.

Note 2: The oscillatory motions are defined as $a = a_0 \sin \omega t$ and $\delta = \delta_0 \sin \omega t$. The equation for a corresponding oscillatory pressure (including higher harmonics, if available) reads:

$p(t) = p_m + p' \sin \omega t + p'' \cos \omega t + p'_1 \sin 2\omega t + p''_1 \cos 2\omega t + \text{etc.}$
 Similar expressions hold for the aerodynamic coefficients.

TABLE 4.1
 Contour data of the NLR 7301 airfoil

UPPER PART			LOWER PART			
X	Z	X	Z	X	Z	
0.0000012	-0.0004167	0.4297667	+0.000474	-0.0000016	0.6594675	-0.0725326
0.0002805	+0.052101	0.4184044	+0.0743457	-0.0002342	0.6088157	-0.0717156
0.0004870	+0.0747749	0.4476479	+0.0761984	-0.0004347	0.6765406	-0.0711708
0.00068461	+0.094945	0.4547211	+0.0761024	-0.0006463	0.6456332	-0.0703267
0.00088152	+0.112217	0.4445101	+0.0723278	-0.0008431	0.6431971	-0.0693156
0.00107842	+0.124317	0.4728411	+0.0644999	-0.0102200	0.5001765	-0.0683176
0.00127535	+0.138934	0.4406039	+0.0672375	-0.0121494	0.5067021	-0.0675118
0.00147229	+0.150411	0.4444151	+0.0644227	-0.0121076	0.5133643	-0.0666367
0.00166924	+0.160874	0.44966470	+0.0641171	-0.0133289	0.5202244	-0.0656733
0.00186621	+0.170736	0.4526110	+0.0649437	-0.0131103	0.5174553	-0.0646685
0.00205314	+0.179479	0.4500174	+0.0655260	-0.0146686	0.5151272	-0.0635151
0.00225004	+0.1720574	0.4518101	+0.0642397	-0.0151403	0.5431744	-0.0623171
0.00244691	+0.1554172	0.4522442	+0.0643493	-0.0169304	0.5916579	-0.0609973
0.00264389	+0.1247722	0.45102975	+0.0581152	-0.0164134	0.5565499	-0.0605236
0.00284162	+0.1051111	0.4517131	+0.0579355	-0.0175153	0.5641617	-0.0593073
0.00303949	+0.0926872	0.4518482	+0.0576577	-0.0175490	0.5729834	-0.0575037
0.00323730	+0.0846501	0.4525601	+0.0570114	-0.0219767	0.5421558	-0.0559511
0.00343513	+0.0761504	0.4513241	+0.0562147	-0.0230951	0.5316240	-0.0541883
0.00363311	+0.0678669	0.45485577	+0.0516652	-0.0245999	0.6011052	-0.0523314
0.00383119	+0.0578669	0.45780632	+0.0472171	-0.0251330	0.6105822	-0.0505882
0.00402919	+0.0471474	0.4512274	+0.0487567	-0.0261107	0.6192513	-0.0487740
0.00422709	+0.0364004	0.4444551	+0.0421711	-0.0271153	0.6284652	-0.0465161
0.00442519	+0.0264636	0.4533456	+0.0373221	-0.0304212	0.6374225	-0.0451561
0.00462313	+0.0174147	0.4519741	+0.0379224	-0.0311740	0.6468466	-0.0433366
0.00482102	+0.0084552	0.4500016	+0.0377706	-0.0327561	0.6559535	-0.0416449
0.005020255	+0.0050761	0.4509746	+0.0372373	-0.0335576	0.6637243	-0.0391643
0.00521870	+0.0065761	0.4513285	+0.0379517	-0.0355635	0.6727506	-0.0376306
0.00541712	+0.0047230	0.4514781	+0.0377146	-0.0373205	0.6841604	-0.0356173
0.00561550	+0.0026451	0.4524604	+0.0365106	-0.0371306	0.6947934	-0.0335749
0.00581357	+0.0004804	0.4529261	+0.0356153	-0.0361341	0.7011244	-0.0311044
0.00601154	+0.0003754	0.4540119	+0.0356774	-0.0351666	0.7114464	-0.0298954
0.00620950	+0.0003694	0.4542674	+0.0351483	-0.0347723	0.7223530	-0.0288371
0.00640753	+0.0003683	0.4545019	+0.0351371	-0.0341950	0.7329245	-0.0276690
0.00660549	+0.0003684	0.4546476	+0.0352344	-0.0342107	0.7437504	-0.0264174
0.00680347	+0.0003684	0.4547261	+0.0351151	-0.0341217	0.7545032	-0.0254173
0.00700145	+0.0003684	0.4547961	+0.0351116	-0.0333205	0.7652613	-0.0247132
0.00720043	+0.0003684	0.4550048	+0.0351152	-0.0331306	0.7760273	-0.0240666
0.00740041	+0.0003684	0.4552021	+0.0351153	-0.0329033	0.7868331	-0.0231576
0.00760039	+0.0003684	0.4554007	+0.0351153	-0.0327221	0.7962633	-0.0217842
0.00780037	+0.0003684	0.4556004	+0.0351153	-0.0325232	0.8060046	-0.0206663
0.00800035	+0.0003684	0.4558001	+0.0351153	-0.0323221	0.8157264	-0.0195202
0.00820033	+0.0003684	0.4560001	+0.0351153	-0.0321211	0.8254343	-0.0184061
0.00840031	+0.0003684	0.4562001	+0.0351153	-0.0319201	0.8351201	-0.0173171
0.00860029	+0.0003684	0.4564001	+0.0351153	-0.0317201	0.8448933	-0.0162321
0.00880027	+0.0003684	0.4566001	+0.0351153	-0.0315201	0.8546593	-0.0151431
0.00900025	+0.0003684	0.4568001	+0.0351153	-0.0313201	0.8644263	-0.0140541
0.00920023	+0.0003684	0.4570001	+0.0351153	-0.0311201	0.8741933	-0.0130651
0.00940021	+0.0003684	0.4572001	+0.0351153	-0.0309201	0.8839603	-0.0120751
0.00960019	+0.0003684	0.4574001	+0.0351153	-0.0307201	0.8937273	-0.0110851
0.00980017	+0.0003684	0.4576001	+0.0351153	-0.0305201	0.9035043	-0.0100951
0.01000015	+0.0003684	0.4578001	+0.0351153	-0.0303201	0.9132713	-0.0090951
0.01020013	+0.0003684	0.4580001	+0.0351153	-0.0301201	0.9230383	-0.0080951
0.01040011	+0.0003684	0.4582001	+0.0351153	-0.0299201	0.9328053	-0.0070951
0.01060009	+0.0003684	0.4584001	+0.0351153	-0.0297201	0.9425723	-0.0060951
0.01080007	+0.0003684	0.4586001	+0.0351153	-0.0295201	0.9523393	-0.0050951
0.01100005	+0.0003684	0.4588001	+0.0351153	-0.0293201	0.9621063	-0.0040951
0.01120003	+0.0003684	0.4590001	+0.0351153	-0.0291201	0.9718733	-0.0030951
0.01140001	+0.0003684	0.4592001	+0.0351153	-0.0289201	0.9816403	-0.0020951
0.01160000	+0.0003684	0.4594001	+0.0351153	-0.0287201	0.9914073	-0.0010951
0.01180000	+0.0003684	0.4596001	+0.0351153	-0.0285201	1.0011743	-0.0000951

Note: See note at the end of table 4.2

TABLE 4.2

Actual contour data of the
NLR 7301 airfoil (conf. B)
(measures in mm)

x	z_{upper}	z_{lower}
000.000	000.000	-000.000
000.500	003.250	-002.820
001.000	004.595	-003.780
002.000	006.360	-005.025
003.000	007.750	-005.880
004.000	008.415	-006.525
005.000	009.030	-007.065
006.000	009.520	-007.520
007.000	009.940	-007.930
008.000	010.315	-008.290
009.000	010.640	-008.620
010.000	010.935	-008.920
015.000	012.045	-013.110
020.000	013.380	-010.990
024.000	013.545	-011.695
030.000	014.105	-012.370
040.000	014.545	-013.125
050.000	015.300	-013.620
060.000	015.815	-013.795
070.000	015.910	-013.665
080.000	015.800	-013.190
090.000	015.400	-012.245
100.000	014.910	-010.810
110.000	014.055	-009.030
120.000	012.835	-006.945
130.000	011.240	-004.760
134.500	010.410	-003.785
137.500	009.460	-003.165
140.000	009.450	-002.645
150.000	007.335	-000.780
160.000	005.135	000.495
170.000	002.935	000.975
175.000	001.855	000.860
180.000	000.775	000.465

Note regarding Tables 4.1 and 4.2: In Ref. 4.7 the contour coordinates have been transformed to unit chord. The model was designed to shape given by Table 4.1, but the trailing edge was cut off at $x/c = 1.0$. The actual measured shape of the model is given in the table above.

TABLE 4.3

Test program for the NLR 7301 airfoil (conf. A)

Basic program: amplitude of oscillation: $a_0 = 0.5$ degree
frequencies: 0, 10 and 80 Hz
transition strip at $x/c = 0.3$

Incidence	MACH NUMBER									
	.5	.4	.65	.675	.70	.725	.74	.75	.76	.775
$a_m = 0^\circ$	x			x		x		x		x
0.50	x	x	x	x	x	x	x	x	x	x
1.50	x			x		x		x		x
3.00	x	x	x	x	x	x	x	x	x	x

Influence of amplitude and frequency transition strip at $x/c = 0.3$

Incidence	amplitude a_0	freq.	MACH NUMBER	
		.5 .7 .75		
$a_m = 0.85^\circ$	0.1; 0.25; 0.75; 1.0; 1.5°	10; 80 Hz	x x x	
	3.00	0.1; 0.25; 0.75; 1.0	10; 80	x
0.85°	0.5; 1.0°	10; 30; 60; 80 Hz	x x x	
	3.00	0.5; 1.0	10; 30; 60; 80	x

Additional tests with natural transition

Incidence	amplitude a_0	freq.	MACH NUMBER
		.5 .7 .75	
$a_m = 0.85^\circ$	0.5; 1.0°	10 Hz	x x x
	0.5; 0.75	80	x x x
3.00	0.5; 1.0	10	x
	0.5; 0.75	80	x
0.85	0.5	30; 60	x x

TABLE 4.4
Test cases for the NLR 7301 airfoil (cases A and B) included in Data Set 4

No.	Flow	No.	N	CF Case			Run No	N	α_m	δ_m	α_o	δ_o	Re	$Re \cdot 10^{-6}$	Trans.	Harm.	Table
				a_m	a_o	κ											
Pitching about 0.4 c (casef. A)	Subsonic	1	0.500	0.10	0.5	0	12201	0.499	0.85	0.50	0	1.70	0.3	c	1	4.5	
		1	0.500	0.10	0.5	0.058	1601	0.499	0.85	0.55	0.098	1.70	0.3	c	1	4.6	
		2	0.500	0.10	0.5	0.262	1301	0.498	0.35	0.44	0.362	1.70	0.3	c	1	4.7	
	Transonic with shock	2	0.700	2.00	0.5	0	14405	0.696	3.30	0.50	0	2.11	0.3	c	1	4.8	
		3	0.700	2.00	0.5	0.072	3805	0.696	3.00	0.42	0.072	2.11	0.3	c	1	4.9	
		4	0.700	2.00	1.0	0.072	3905	0.696	3.00	0.98	0.072	2.11	0.3	c	1	4.10	
		5	0.700	2.00	0.5	0.192	52705	0.695	3.00	0.55	0.192	2.12	0.3	c	1	4.11	
	Supersonic design	3	0.721	-0.19	0.5	0	16008	0.744	0.85	0.50	0	2.11	0.3	c	1	4.12	
		6	0.721	-0.19	0.5	0.068	9608	0.744	0.85	0.46	0.068	2.23	free	1	4.13		
		7	0.721	-0.19	1.0	0.068	9608	0.744	0.85	No measurement	0.61	0.181	2.22	free	1	4.14	
Pleg rotation (casef. B)	Subsonic	10	0.500	0.10	1.0	0	250	0.503	0	0.02	0.95	0	1.69	0.07	c	1	4.15
		10	0.500	0.10	1.0	0.098	253	0.502	0	0.02	0.97	0.098	1.69	0.07	c	1	4.16
		11	0.700	2.00	1.0	0	129	0.702	3.00	-0.08	0.95	0	2.14	0.3	c	1	4.17
	Transonic with shock	11	0.700	2.00	1.0	0.071	120	0.701	3.00	0.03	0.97	0.071	2.14	0.3	c	1	4.18
		12	0.721	-0.19	1.0	0.067	160	0.754	0.85	0.01	0.96	0	2.23	free	1	4.19	
		13	0.721	-0.19	1.0	0.161	148-150	0.755	0.85	No measurement	0.95	0.061	2.23	free	1,2,3	4.20-4.22	
	Supersonic design	14	0.721	-0.19	1.0	0.465	162	0.756	3.85	-0.01	0.90	0.445	2.23	free	1	4.23	

Remarks on Table 4.4

Cases 21 to 26 are extra to the computational cases identified in Ref. 4.7. They correspond to zero-frequency ($\kappa = 0$) experimental data that are closely related to the CF Cases for which $\kappa \neq 0$.
The asterisks denote Priority Cases.

TABLE 4.5

RUN 12201

M	.499	C2	.50		STAT.		QUASI-INSTAT.	
ALPHA	.85	FREQ	0.				RE	IM
P0	10376.	K	0.000		CL	.303	1.835	0.003
RE	1.70E6				CM	.068	-.076	0.000
Q	1524.							

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	-.068	.516	-12.204	0.000	.284	.420	11.230	0.000
.05	-1.148	.771	-12.834	0.000	-.369	.591	9.511	0.000
.10	-.859	.705	-9.225	0.000	-.372	.591	6.417	0.000
.15	-.683	.665	-5.214	0.000	-.386	.595	5.099	0.000
.20	-.647	.657	-5.099	0.000	-.403	.599	4.469	0.000
.25	-.626	.652	-4.183	0.000	-.421	.603	3.933	0.000
.30	-.635	.654	-3.495	0.000	-.417	.602	3.151	0.000
.35	-.594	.644	-2.979	0.000	-.429	.605	2.922	0.000
.40	-.587	.643	-2.636	0.000	-.444	.609	2.693	0.000
.45	-.579	.641	-2.235	0.000	-.445	.609	2.177	0.000
.50	-.570	.639	-2.063	0.000	-.397	.597	1.833	0.000
.55	-.556	.635	-1.776	0.000	-.300	.574	1.318	0.000
.60	-.539	.631	-1.261	0.000	-.203	.550	1.089	0.000
.65	-.491	.620	-.859	0.000	-.086	.521	.688	0.000
.70	-.408	.600	-.458	0.000	.029	.491	.630	0.000
.75	-.307	.576	-.286	0.000	.129	.464	.458	0.000
.80	-.193	.548	-.115	0.000	.208	.442	.401	0.000
.85	-.086	.521	.057	0.000	.269	.425	.458	0.000
.90	.012	.496	-.057	0.000	.298	.416	.286	0.000
.95	.089	.475	-.516	0.000	.301	.415	.115	0.000

TABLE 4.6

RUN 1601

M	.499	C2	.55		STAT.		INSTAT.	
ALPHA	.85	FREQ	30.				RE	IM
P0	10398.	K	.098		CL	.311	1.481	-.170
RE	1.70E6				CM	.069	-.028	.151
Q	1529.							

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	-.070	.518	-10.360	2.296	.296	.417	6.804	-3.146
.05	-1.163	.776	-11.456	2.389	-.351	.586	7.090	-2.048
.10	-.846	.703	-8.108	1.833	-.373	.592	4.808	-1.920
.15	-.707	.672	-3.138	.552	-.383	.594	4.104	-1.096
.20	-.654	.659	-4.000	.853	-.400	.598	3.403	-.864
.25	-.633	.655	-3.339	.514	-.415	.602	2.894	-.738
.30	-.642	.657	-2.972	.213	-.413	.601	2.725	-.614
.35	-.599	.647	-2.920	.004	-.426	.604	2.671	.011
.40	-.594	.645	-2.414	.024	-.440	.608	2.356	.164
.45	-.582	.643	-2.089	-.054	-.440	.608	1.963	.091
.50	-.571	.640	-1.804	-.181	-.393	.597	1.688	.237
.55	-.562	.638	-1.398	-.139	-.297	.573	1.492	.238
.60	-.542	.633	-1.045	-.155	-.201	.560	1.089	.164
.65	-.494	.622	-.705	-.200	-.084	.520	.852	.296
.70	-.410	.602	-.412	-.227	-.030	.491	.259	-.067
.75	-.307	.577	-.191	-.277	.130	.464	.547	.422
.80	-.193	.549	.054	-.279	.212	.441	.571	.457
.85	-.085	.522	.091	-.256	.269	.425	.562	.533
.90	.011	.497	-.090	-.152	.300	.416	.440	.431
.95	.086	.477	-.466	-.099	.302	.415	.250	.284

TABLE 4.7

RUN 1301

M	.498	C2	.44	STAT.	INSTAT.
ALPHA	.85	FREQ	.80.	RE	IM
P0	10398.	K	.262	CL	.290
RF	1.70E6			CM	.071
Q	1524.				

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	-.014	.502	-9.118	4.392	.248	.431	5.363	-3.002
.05	-1.106	.760	-8.298	3.528	-.400	.598	5.742	-2.356
.10	-.806	.692	-6.065	1.829	-.402	.598	3.390	-1.596
.15	-.693	.666	-2.099	-.165	-.408	.600	3.630	-1.041
.20	-.637	.653	-3.772	.745	-.418	.602	3.043	-.636
.25	-.620	.649	-3.161	.289	-.436	.606	2.558	-.359
.30	-.635	.653	-2.886	-.023	-.431	.605	2.217	-.317
.35	-.594	.643	-2.839	-.250	-.441	.608	2.911	.124
.40	-.588	.642	-2.251	.357	-.452	.610	2.829	.443
.45	-.576	.639	-1.996	-.462	-.451	.610	2.216	.503
.50	-.570	.638	-1.819	-.556	-.402	.598	2.062	.727
.55	-.562	.636	-1.352	-.610	-.304	.575	1.573	.807
.60	-.544	.631	-1.034	-.643	-.206	.551	1.132	.821
.65	-.499	.621	-.663	-.645	-.089	.521	1.005	1.079
.70	-.415	.601	-.526	-.690	.026	.491	.177	.151
.75	-.313	.577	-.321	-.748	.128	.464	.999	1.244
.80	-.200	.549	-.102	-.749	.209	.442	1.125	1.202
.85	-.091	.521	-.057	-.714	.266	.425	1.367	1.166
.90	.007	.496	-.158	-.561	.299	.416	.932	.836
.95	.085	.475	-.481	-.048	.301	.415	.488	.450

TABLE 4.8

RUN 14405

M	.696	C2	.50	STAT.	QUASI-INSTAT.
ALPHA	3.00	FREQ	n.	RE	TM
P0	10220.	K	0.000	CL	.715
RF	2.11FA			CM	.074
Q	2509.				

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	.004	.695	-5.500	0.000	.601	.449	6.474	0.000
.05	-1.661	1.398	-7.219	0.000	-.092	.781	7.907	0.000
.10	-1.671	1.403	-7.850	0.000	-.201	.773	6.704	0.000
.15	-1.607	1.368	-8.021	0.000	-.258	.794	5.844	0.000
.20	-1.562	1.344	-8.308	0.000	-.312	.814	5.386	0.000
.25	-1.536	1.331	-9.969	0.000	-.356	.831	5.042	0.000
.30	-1.508	1.316	-11.803	0.000	-.373	.837	4.813	0.000
.35	-1.518	1.321	-22.746	0.000	-.409	.851	4.183	0.000
.40	-1.406	1.266	-57.640	0.000	-.453	.868	3.896	0.000
.45	-1.585	.918	-49.790	0.000	-.465	.872	3.323	0.000
.50	-.576	.915	1.318	0.000	-.412	.852	2.922	0.000
.55	-.631	.936	9.626	0.000	-.290	.806	2.177	0.000
.60	-.645	.941	8.652	0.000	-.169	.760	1.604	0.000
.65	-.589	.920	8.214	0.000	-.044	.713	1.261	0.000
.70	-.471	.875	2.693	0.000	.079	.666	1.089	0.000
.75	-.337	.824	1.318	0.000	.184	.625	.974	0.000
.80	-.200	.777	.458	0.000	.267	.592	.917	0.000
.85	-.075	.725	-.057	0.000	.324	.569	.889	0.000
.90	.032	.684	-.286	0.000	.386	.586	.743	0.000
.95	.114	.653	-.286	0.000	.354	.557	.630	0.000

TABLE 4.9

RUN 3805

	M	.696	C2	.42	STAT.	INSTAT.
	ALPHA	3.00	FREW	30.	RE	IM
	P0	10220.	K	.072	CL	.705
RE	2.11E6				CM	.072
W	2505.					.296
						.106

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPHE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	.001	.695	-4.068	1.563	.605	.447	4.478	-2.528
.05	-1.669	1.398	-6.156	1.863	-.084	.728	6.187	-2.665
.10	-1.682	1.405	-9.320	1.586	-.200	.772	4.633	-2.478
.15	-1.622	1.372	-9.811	1.036	-.259	.794	4.408	-2.078
.20	-1.572	1.346	-9.516	2.170	-.315	.815	3.680	-2.034
.25	-1.554	1.326	-8.715	2.920	-.364	.833	3.458	-1.909
.30	-1.478	1.298	-10.091	5.812	-.385	.841	2.353	-2.017
.35	-1.463	1.290	-14.295	8.129	-.413	.852	3.045	-1.367
.40	-1.122	1.134	-74.021	40.662	-.448	.865	4.448	-1.226
.45	-.721	.969	-34.136	3.267	-.466	.872	3.831	-1.196
.50	-.620	.930	-.667	-6.649	-.410	.851	3.454	-.855
.55	-.622	.931	10.303	-6.913	-.289	.805	2.630	-.647
.60	-.631	.934	8.852	-5.420	-.170	.760	2.305	-.552
.65	-.574	.914	5.066	-3.002	-.044	.713	1.858	-.322
.70	-.464	.871	2.838	-1.691	-.079	.666	.353	-.393
.75	-.335	.821	1.978	-1.062	.183	.625	1.575	.765
.80	-.198	.770	1.026	-.487	.264	.593	1.795	.192
.85	-.073	.725	.435	-.362	.323	.569	1.826	.310
.90	.035	.683	.022	-.473	.304	.556	1.565	.068
.95	.112	.652	-.369	-.596	.353	.557	1.153	-.251

TABLE 4.10

RUN 3905

	M	.696	C2	.48	STAT.	INSTAT.
	ALPHA	4.00	FREW	30.	RE	IM
	P0	10220.	K	.072	CL	.702
RE	2.31E6				CM	.072
W	2509.					.306
						.005

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPHE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	.013	.691	-4.005	1.351	.604	.447	3.921	-2.109
.05	-1.664	1.399	-5.626	1.316	-.084	.728	5.063	-2.194
.10	-1.686	1.411	-8.972	1.172	-.202	.778	4.267	-2.127
.15	-1.622	1.375	-7.543	1.655	-.263	.796	4.328	-1.770
.20	-1.554	1.339	-6.761	2.275	-.319	.817	3.697	-1.785
.25	-1.412	1.317	-8.630	2.748	-.367	.835	3.240	-1.686
.30	-1.455	1.288	-9.320	3.526	-.384	.841	3.033	-1.784
.35	-1.229	1.180	-31.991	17.920	-.416	.854	3.653	-1.288
.40	-1.110	1.180	-34.780	18.621	-.432	.867	4.728	-1.081
.45	-.981	1.055	-23.753	10.022	-.468	.875	3.495	-1.059
.50	-.746	.981	-7.757	-1.004	-.413	.853	3.930	-.752
.55	-.669	.980	2.002	-3.133	-.292	.807	2.311	-.956
.60	-.610	.927	6.394	-4.290	-.172	.762	1.798	-.610
.65	-.552	.905	5.043	-2.065	-.046	.714	1.468	-.288
.70	-.446	.805	3.157	-1.810	-.077	.687	.512	-.349
.75	-.320	.817	1.674	-.900	.102	.626	1.273	-.002
.80	-.190	.768	.796	-.447	.262	.594	1.331	.130
.85	-.070	.723	.141	-.279	.320	.571	1.368	.171
.90	.031	.684	-.086	-.333	.351	.558	1.191	.037
.95	.107	.655	-.114	-.696	.351	.558	1.024	-.280

TABLE 4.11

RUN 52705

M .695	C2 .55	STAT.	INSTAT.
ALPHA 3.00	FREQ 80.		
P0 10265.	K .192	CL .694	RE 1.541 IM -.909
RE 2.12E6		CM .072	.210 .087
Q 2511.			

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	.010	.691	-2.639	1.667	.599	.448	2.724	-1.662
.05	-1.657	1.389	-4.196	2.153	-.095	.730	3.438	-1.706
.10	-1.667	1.325	-3.680	1.892	-.206	.772	2.436	-.983
.15	-1.604	1.361	-6.745	3.486	-.267	.795	2.347	-.805
.20	-1.557	1.316	-5.944	3.449	-.323	.816	2.223	-.693
.25	-1.520	1.317	-5.168	3.809	-.368	.833	1.997	-.502
.30	-1.458	1.241	-3.517	3.595	-.390	.841	1.267	.136
.35	-1.454	1.284	-6.493	12.094	-.417	.852	2.171	.180
.40	-1.038	1.122	-19.161	42.695	-.453	.865	2.266	.372
.45	-6.67	.953	-12.598	9.450	-.473	.872	2.020	.199
.50	-6.60	.924	-2.708	-5.711	-.415	.851	1.870	.002
.55	-6.26	.931	1.611	-7.332	-.294	.805	1.907	.163
.60	-6.39	.936	1.749	-9.694	-.173	.760	1.210	.254
.65	-5.85	.916	1.457	-3.256	-.344	.711	1.104	.418
.70	-4.68	.871	.874	-2.002	-.076	.665	.225	.067
.75	-3.34	.821	.739	-1.362	.162	.624	1.358	.411
.80	-1.199	.770	.690	-.049	.264	.592	1.982	.293
.85	-0.74	.723	.345	-.510	.524	.567	1.870	.247
.90	-0.32	.682	.125	-.354	.355	.355	1.404	.036
.95	.112	.652	-.284	-.290	.354	.355	.788	-.166

TABLE 4.12

RUN 16400

M .744	C2 .50	STAT.	QUASI-INSTAT.
ALPHA .45	FREQ 0.		
P0 10332.	K 0.000	CL .481	RE 3.522 IM 0.000
RE 2.22E6		CM .108	1.239 0.000
Q 2772.			

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.01	.328	.607	-5.214	0.000	.742	.604	.193	0.000
.05	-1.101	1.229	-11.230	0.000	-.490	.424	11.001	0.000
.10	-1.140	1.259	-8.652	0.000	-.486	.464	9.663	0.000
.15	-1.173	1.234	-10.943	0.000	-.316	.499	7.964	0.000
.20	-1.074	1.217	-14.497	0.000	-.464	.970	7.735	0.000
.25	-1.060	1.208	-18.022	0.000	-.612	1.000	5.652	0.000
.30	-1.047	1.201	-21.944	0.000	-.624	1.005	7.047	0.000
.35	-1.037	1.197	-16.335	0.000	-.681	1.017	7.907	0.000
.40	-1.039	1.197	-18.392	0.000	-.676	1.028	7.047	0.000
.45	-1.046	1.201	-19.154	0.000	-.660	1.021	5.157	0.000
.50	-1.062	1.209	-17.762	0.000	-.587	.477	4.123	0.000
.55	-1.043	1.201	-16.157	0.000	-.398	.892	2.235	0.000
.60	-1.003	1.179	-12.777	0.000	-.184	.820	2.003	0.000
.65	-1.788	1.078	-14.610	0.000	-.034	.788	1.662	0.000
.70	-4.493	.927	-2.349	0.000	-.004	.788	1.662	0.000
.75	-4.307	.871	1.379	0.000	.103	.648	2.015	0.000
.80	-1.176	.817	-.206	0.000	.261	.626	1.891	0.000
.85	-0.934	.766	-.816	0.000	.342	.600	1.891	0.000
.90	-0.683	.710	-.401	0.000	.745	.581	2.120	0.000
.95	-1.162	.677	2.005	0.000	.394	.576	2.177	0.000

TABLE 4.13

RUN 9608

M .744	C2 .46	STAT.	INSTAT.
ALPHA .85	FREQ 30.	RE	IM
P0 10380.	K .068	CL .463	2.710 -.914
RE 2.23E6		CM .105	.157 .074
0 2785.			

UPPERSIDE					LOWERSIDE				
X/C	CP+	M+	CPHE+	CPIM+	CP-	M-	CPRE-	CPIM-	
.01	.329	.605	-3.845	1.210	.332	.604	4.500	-2.394	
.05	-1.093	1.225	-8.934	2.739	-.435	.924	7.494	-2.975	
.10	-1.153	1.257	-8.638	1.809	-.486	.945	6.085	-2.661	
.15	-1.111	1.234	-8.954	1.699	-.517	.959	6.092	-2.130	
.20	-1.062	1.210	-7.623	3.184	-.566	.980	5.631	-2.170	
.25	-1.041	1.199	-8.752	3.917	-.619	1.003	5.684	-2.346	
.30	-1.023	1.190	-10.687	4.692	-.627	1.006	6.345	-1.730	
.35	-1.009	1.184	-12.728	6.138	-.652	1.017	6.361	-1.423	
.40	-1.012	1.185	-12.752	7.085	-.687	1.032	5.064	-1.614	
.45	-1.011	1.185	-14.213	8.315	-.665	1.023	3.797	-1.090	
.50	-1.007	1.182	-18.586	11.621	-.564	.979	2.687	-.537	
.55	-1.030	1.194	-13.956	8.802	-.360	.892	.816	.038	
.60	-1.030	1.194	-9.947	1.031	-.187	.821	.393	.102	
.65	-1.722	1.049	20.134	-12.438	-.035	.758	.049	.119	
.70	-4.449	.931	6.371	-4.040	.096	.704	.111	-.043	
.75	-2.297	.867	3.078	-1.595	.200	.660	1.217	.352	
.80	-1.168	.813	1.813	-.455	.276	.628	1.495	.433	
.85	-0.848	.764	.563	-.076	.337	.602	1.636	.497	
.90	.061	.719	-.646	-.127	.375	.585	1.032	.167	
.95	.150	.692	-1.429	-.302	.387	.580	.319	-.168	

TABLE 4.14

RUN 6706

M .744	C2 .61	STAT.	INSTAT.
ALPHA .85	FREQ 60.	RE	IM
P0 10383.	K .161	CL .471	1.478 -.586
RE 2.22E6		CM .104	.259 .255
0 2770.			

UPPERSIDE					LOWERSIDE				
X/C	CP+	M+	CPHE+	CPIM+	CP-	M-	CPRE-	CPIM-	
.01	.323	.608	-2.485	1.472	.338	.601	2.747	-1.772	
.05	-1.107	1.231	-6.763	3.710	-.428	.921	5.809	-2.291	
.10	-1.167	1.263	-3.628	1.801	-.484	.944	5.170	-1.887	
.15	-1.125	1.240	-5.436	2.970	-.511	.956	5.285	-1.459	
.20	-1.077	1.216	-6.085	3.026	-.563	.978	5.051	-1.256	
.25	-1.059	1.207	-4.057	3.993	-.607	.997	2.934	-1.079	
.30	-1.043	1.198	-4.510	4.794	-.622	1.003	3.645	-.763	
.35	-1.032	1.183	-6.300	6.039	-.642	1.012	3.599	-.252	
.40	-1.032	1.193	-5.802	6.536	-.677	1.028	2.039	.183	
.45	-1.031	1.193	-3.531	7.356	-.657	1.019	2.138	.471	
.50	-1.018	1.189	-2.966	10.747	-.558	.976	1.389	1.235	
.55	-1.014	1.184	-5.064	9.904	-.339	.892	.857	1.266	
.60	-0.994	1.175	-6.754	1.791	-.167	.820	.239	1.134	
.65	-0.673	1.027	-6.213	-14.659	-.033	.738	.135	1.316	
.70	-0.450	.930	-.572	-6.001	.096	.704	.092	.222	
.75	-0.303	.869	-1.383	-2.949	.102	.659	1.319	.964	
.80	-0.171	.814	-1.351	-1.819	.278	.627	1.716	.463	
.85	-0.050	.764	-.889	-1.202	.339	.601	1.907	.339	
.90	.060	.719	-.004	-.493	.380	.583	1.033	.295	
.95	.149	.692	-0.773	-.350	.388	.579	.302	.267	

TABLE 4.15

Pressure distributions for NLR 7301 with control surface and transition strip at $x/c = .07$
ZERO FREQUENCY TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	UPPERSIDE				LOVERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.010	.121	.470	-2.816	.000	.067	.485	3.157	.000
.030	-.940	.730	-4.084	.000	-.467	.619	3.189	.000
.050	-.873	.715	-3.457	.000	-.535	.636	2.607	.000
.100	-.627	.657	-2.129	.000	-.465	.619	2.207	.000
.150	-.568	.644	-1.839	.000	-.468	.620	1.846	.000
.200	-.544	.638	-1.718	.000	-.474	.621	1.706	.000
.250	-.533	.635	-1.670	.000	-.481	.623	1.646	.000
.300	-.523	.633	-1.622	.000	-.489	.625	1.645	.000
.350	-.511	.630	-1.597	.000	-.485	.624	1.645	.000
.400	-.509	.630	-1.621	.000	-.496	.626	1.685	.000
.450	-.504	.628	-1.597	.000	-.483	.623	1.786	.000
.500	-.500	.627	-1.693	.000	-.430	.611	1.807	.000
.550	-.489	.625	-1.766	.000	-.328	.586	1.768	.000
.600	-.469	.620	-1.958	.000	-.222	.560	1.770	.000
.650	-.421	.608	-2.102	.000	-.109	.531	1.812	.000
.700	-.340	.589	-2.389	.000	.008	.501	1.854	.000
.725	-.286	.576	-2.509	.000	.053	.489	1.854	.000
.750	-.271	.572	-3.496	.000	.115	.472	1.975	.000
.775	-.235	.563	-2.580	.000	.138	.465	1.635	.000
.800	-.171	.547	-1.761	.000	.174	.455	1.355	.000
.850	-.067	.520	-1.013	.000	.227	.440	.955	.000
.900	.020	.498	-.361	.000	.259	.431	1.016	.000
.950	.097	.477	-.408	.000	.269	.428	.575	.000

TEST DATA	MODEL DATA	OVERALL DATA	STEADY	UNSTEADY
			RE	IM
MEETRUNNR. 250	ALPHA .00 DEG.			
MACH .503	DELTA .02 DEG.	NORMAL FORCE CL	.173	1.090 .000
Q (PA) 15004	ANPL. .95 DEG.	MOHENT(1/4C) CH	.058	.393 .000
RE 1.69E6	FREQ. .0 Hz	FLAP FORCE RC	.0625	.1634 .0000
HARM 1	Rfreq .000	HINGE MOMENT NC	.0059	.0246 .0000
IDENTNR. 10				

TABLE 4.16

FUNDAMENTAL FREQUENCY TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	UPPERSIDE				LOVERSIDE			
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-	CPIM-
.010	-.126	.469	-2.159	1.234	.069	.484	2.243	-1.519
.030	-.933	.728	-3.015	1.537	-.464	.618	2.673	-1.422
.050	-.867	.713	-.683	1.411	-.531	.634	.973	-1.323
.100	-.629	.638	-1.930	.987	-.172	.620	1.900	-.860
.150	-.570	.643	-1.384	.795	-.471	.620	1.389	-.039
.200	-.545	.638	-1.238	.629	-.474	.621	1.321	-.673
.250	-.534	.635	-1.237	.629	-.483	.623	1.291	-.368
.300	-.522	.632	-1.363	.683	-.488	.624	.976	-.584
.350	-.512	.630	-1.362	.684	-.488	.624	1.306	-.447
.400	-.509	.629	-1.290	.421	-.497	.626	1.419	-.439
.450	-.503	.628	-1.425	.411	-.483	.623	1.418	-.439
.500	-.501	.627	-1.551	.266	-.431	.610	1.521	-.320
.550	-.487	.624	-1.350	.266	-.326	.589	1.622	-.201
.600	-.470	.620	-1.820	.247	-.222	.599	1.776	-.024
.650	-.421	.608	-1.956	.239	-.107	.530	1.929	.152
.700	-.340	.588	-2.347	.078	.009	.500	1.970	.319
.725	-.283	.574	-2.416	.144	.037	.487	1.975	.205
.750	-.269	.571	-2.494	.072	.117	.471	2.123	.492
.775	-.233	.562	-2.728	-.215	.140	.465	1.748	.671
.800	-.172	.547	-1.711	-.213	.174	.453	1.565	.456
.850	-.067	.520	-.901	-.159	.228	.460	1.119	.429
.900	.022	.497	-.368	-.069	.261	.430	.955	.362
.950	.097	.476	-.423	-.194	.270	.428	.517	.223

TEST DATA	MODEL DATA	OVERALL DATA	STEADY	UNSTEADY
			RE	IM
MEETRUNNR. 253	ALPHA .00 DEG.			
MACH .502	DELTA .02 DEG.	NORMAL FORCE CL	.172	.927 -.197
Q (PA) 15024	ANPL. .97 DEG.	MOHENT(1/4C) CH	.058	.418 .063
RE 1.69E6	FREQ. 30.0 Hz	FLAP FORCE RC	.0623	.1703 .0376
HARM 1	Rfreq .098	HINGE MOMENT NC	.0059	.0255 .0077
IDENTNR. 10				

TABLE 4.17

ZERO FREQUENCY TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	CP+	UPPERSIDE			LOWERSIDE			CPIM-
		M+	CPRE+	CPIH+	CP-	M-	CPRE-	
.010	.009	.699	-.832	.000	.583	.461	1.305	.000
.030	-1.467	1.312	-.984	.000	.055	.681	1.750	.000
.050	-1.597	1.381	-1.214	.000	-.107	.743	1.775	.000
.100	-1.562	1.361	-1.078	.000	-.208	.782	1.574	.000
.150	-1.501	1.329	-1.345	.000	-.259	.801	1.550	.000
.200	-1.459	1.307	-1.522	.000	-.312	.821	1.614	.000
.250	-1.430	1.293	-2.411	.000	-.356	.838	1.644	.000
.300	-1.302	1.230	-10.641	.000	-.380	.847	1.683	.000
.350	-.857	1.035	-23.199	.000	-.424	.864	1.890	.000
.400	-.633	.945	-3.794	.000	-.466	.880	2.258	.000
.450	-.616	.939	.741	.000	-.476	.884	2.263	.000
.500	-.641	.949	.823	.000	-.423	.864	2.263	.000
.550	-.638	.947	-.449	.000	-.304	.818	1.914	.000
.600	-.605	.934	-1.202	.000	-.188	.774	1.957	.000
.650	-.506	.896	-1.699	.000	-.062	.726	1.971	.000
.700	-.381	.848	-1.984	.000	.063	.678	2.036	.000
.725	-.307	.819	-2.121	.000	.117	.657	2.063	.000
.760	-.252	.799	-2.488	.000	.178	.633	2.235	.000
.775	-.217	.785	-1.813	.000	.205	.622	1.847	.000
.800	-.152	.760	-1.168	.000	.245	.606	1.503	.000
.850	-.042	.718	-.743	.000	.305	.582	1.110	.000
.900	.044	.685	-.785	.000	.338	.568	.874	.000
.950	.106	.661	-1.093	.000	.337	.568	.423	.000

TEST DATA	MODEL DATA	OVERALL DATA	STEADY	UNSTEADY
MEETRUNNR. 129	ALPHA 3.00 DEG.	NORMAL FORCE CL	.593	RE 1.410 IN .000
MACH .702	DELTA -.08 DEG.	HOMENT(1/4C) CH	.052	.484 .000
Q (PA) 250.75	AMPL. .95 DEG.	FLAP FORCE RC	.0743	.1615 .0000
RE 2.14E6	FREQ. .0 HZ	HINGE MOMENT HC	.0073	.0282 .0000
HARM 1	HFREQ .000			
IDENTNR. 5				

TABLE 4, 18

FUNDAMENTAL FREQUENCY TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	CP+	UPPERSIDE			LOIVERSIDE			
		H+	CPRE+	CPIH+	CP-	H-	CPRE-	CPIH-
.010	.006	.699	-.709	.568	.584	.460	.940	-.829
.030	-1.472	1.312	-.982	.945	.039	.679	1.853	-.694
.050	-1.600	1.380	-1.121	.833	-.195	.742	.646	-1.057
.100	-1.559	1.358	-.887	.703	-.207	.781	.762	-.933
.150	-1.500	1.326	-1.116	.992	-.250	.800	.983	-.926
.200	-1.437	1.305	-1.220	1.009	-.310	.620	1.000	-.886
.250	-1.426	1.289	-1.726	1.507	-.339	.837	1.097	-.856
.300	-1.272	1.215	-.784	4.385	-.379	.866	1.193	-.853
.350	-1.880	1.043	-17.495	10.740	-.422	.863	1.421	-.861
.400	-1.632	.952	-3.338	.628	-.462	.870	1.319	-.865
.450	-1.622	.940	-.373	-1.670	-.476	.883	1.744	-.846
.500	-1.640	.947	-.030	-1.932	-.422	.843	1.871	-.879
.550	-1.636	.946	-.898	-1.355	-.361	.816	1.933	-.493
.600	-1.599	.931	-1.303	-.861	-.181	.771	1.990	-.339
.650	-1.562	.894	-1.768	-.936	-.058	.724	2.058	-.186
.700	-1.379	.846	-2.032	-.940	.068	.676	2.186	-.030
.725	-1.327	.819	-2.148	-.619	.118	.638	2.181	-.070
.760	-1.235	.799	-2.621	-.252	.173	.634	2.688	-.089
.775	-1.217	.784	-1.908	-.660	.202	.622	2.150	.234
.800	-1.151	.759	-1.198	-.595	.263	.606	1.763	.289
.850	-0.042	.718	-.629	-.362	.306	.582	1.381	.284
.900	.060	.686	-.824	-.169	.337	.568	1.025	.219
.950	.098	.663	-1.304	-.134	.334	.569	.451	.078

TEST DATA	MODEL DATA	OVERALL DATA	STEADY	UNSTEADY
NETTRUNR. 120	ALPHA .300 DEG.	NORMAL FORCE CL	.593	1.213 -.350
MACH .703	DELTA .03 DEG.	MOMENT(1/4C) CH	.053	.016 .009
Q [PA] 25006	ANPL. .97 DEG.	FLAP FORCE NC	.0746	.1783 .0384
RZ 2.1486	FREQ. 30.0 Hz	WINGE MOMENT NC	.0073	.0316 .0046
HARM 1	WINGEQ .071			
IDENTICAL 3				

TABLE 4.19

ZERO FREQUENCY TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	CP+	UPPERSIDE			LOWERSIDE			CPIM-
		M+	CPRE+	CPIN+	CP-	H-	CPRE-	
.010	.329	.613	-.993	.000	.312	.621	1.591	.000
.030	-.958	1.178	-1.801	.000	-.287	.874	2.148	.000
.050	-1.016	1.207	-1.983	.000	-.451	.945	2.308	.000
.100	-1.092	1.246	-1.542	.000	-.512	.971	2.319	.000
.150	-1.034	1.216	-2.036	.000	-.531	.979	2.167	.000
.200	-1.008	1.203	-2.465	.000	-.582	1.002	2.383	.000
.250	-.976	1.186	-3.181	.000	-.623	1.020	2.458	.000
.300	-.956	1.177	-4.652	.000	-.671	1.042	3.444	.000
.350	-.937	1.167	-8.831	.000	-.690	1.051	3.920	.000
.400	-.918	1.158	-8.427	.000	-.732	1.070	4.483	.000
.450	-.872	1.136	-8.701	.000	-.701	1.055	7.333	.000
.500	-.748	1.077	-9.521	.000	-.584	1.003	3.770	.000
.550	-.762	1.083	-7.920	.000	-.376	.912	2.504	.000
.600	-.626	1.022	-5.886	.000	-.204	.839	2.268	.000
.650	-.519	.974	-1.835	.000	-.058	.778	2.313	.000
.700	-.380	.914	-2.003	.000	.077	.721	2.401	.000
.725	-.299	.880	-2.145	.000	.132	.698	2.607	.000
.760	-.249	.859	-2.340	.000	.201	.669	2.467	.000
.775	-.214	.864	-1.779	.000	.228	.657	2.142	.000
.800	-.163	.814	-1.193	.000	.268	.640	1.850	.000
.850	-.024	.764	-.710	.000	.330	.613	1.482	.000
.900	.073	.723	-.917	.000	.369	.596	1.169	.000
.950	.142	.694	-1.268	.000	.372	.594	.670	.000

TEST DATA	MODEL DATA	OVERALL DATA	STEADY	UNSTEADY
			RE	IM
MEETRUNNR. 160	ALPHA .85 DEG.	NORMAL FORCE CL	.352	2.043
MACH .754	DELTA .01 DEG.	MOMENT(1/4C) CH	.076	.814
Q (PA) 27504	ANPL. .96 DEG.	MOMENT(1/4C) CR	.0761	.1870
RE 2.23E6	FREQ. .0 Hz	FLAP FORCE RC	.0073	.0345
HARM 1	RFREQ .000	HINGE MOMENT RC	.0073	.0000
IDENTNR. 6				

TABLE 4.20

FUNDAMENTAL FREQUENCY TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	CP+	UPPERSIDE			LOWERSIDE			CPIM-
		M+	CPRE+	CPIN+	CP-	H-	CPRE-	
.010	.329	.614	-.652	.624	.314	.621	.938	-.1.128
.030	-.936	1.178	-.579	1.044	-.287	.875	1.620	-.1.968
.050	-1.017	1.209	-.284	.925	-.452	.948	.265	-.1.167
.100	-1.090	1.247	-.330	.919	-.512	.972	.404	-.1.298
.150	-1.033	1.217	-.479	1.213	-.510	.980	.385	-.1.323
.200	-1.001	1.201	-.534	1.459	-.575	1.000	.880	-.1.378
.250	-.975	1.168	-.699	1.893	-.621	1.020	.658	-.1.367
.300	-.951	1.176	-.877	2.524	-.672	1.044	.939	-.1.619
.350	-.928	1.165	-.1.392	4.194	-.669	1.051	1.909	-.2.222
.400	-.871	1.137	-.3.247	8.478	-.728	1.069	2.414	-.1.168
.450	-.834	1.119	-.4.606	6.156	-.720	1.065	5.165	-.1.934
.500	-.800	1.103	-.7.824	6.778	-.583	1.004	3.172	-.1.336
.550	-.763	1.085	-.10.308	1.371	-.377	.914	2.132	-.6.900
.600	-.679	1.047	-.8.004	-3.403	-.207	.842	1.983	-.3.59
.650	-.513	.972	-.2.092	-1.180	-.059	.779	2.122	-.2.82
.700	-.371	.911	-.2.063	-.568	.078	.722	2.023	-.3.229
.725	-.295	.879	-.2.266	-.345	.131	.706	2.299	-.2.77
.760	-.238	.853	-.3.377	-.176	.201	.669	2.342	-.1.76
.775	-.205	.861	-.1.706	-.615	.227	.658	2.177	-.0.026
.800	-.137	.812	-.5.909	-.563	.267	.661	1.921	-.0.000
.850	-.022	.766	-.5.514	-.294	.330	.614	1.351	-.0.26
.900	.068	.726	-.1.038	-.251	.369	.596	1.122	-.0.673
.950	.136	.698	-.1.604	-.264	.372	.595	.647	-.1.193

TEST DATA	MODEL DATA	OVERALL DATA	STEADY	UNSTEADY
			RE	IM
MEETRUNNR. 148	ALPHA .85 DEG.	NORMAL FORCE CL	.350	1.325
MACH .755	DELTA .01 DEG.	MOMENT(1/4C) CH	.076	.781
Q (PA) 27538	ANPL. .95 DEG.	MOMENT(1/4C) CR	.0759	.1877
RE 2.23E6	FREQ. 30.0 Hz	FLAP FORCE RC	.0074	.0362
HARM 1	RFREQ .067	HINGE MOMENT RC	.0074	.0032
IDENTNR. 6				

TABLE 4.21

FIRST HARMONIC TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIH+	CP-	M-	CPRE-	CPIH-
.010	.329	.614	-.015	.015	.313	.621	-.047	-.066
.030	-.956	1.178	-.048	.042	-.288	.875	-.045	-.018
.050	-1.014	1.207	-.007	-.005	-.452	.946	.016	.011
.100	-1.090	1.247	.008	.005	-.512	.972	-.043	.001
.150	-1.033	1.217	-.027	.026	-.531	.980	-.033	-.010
.200	-.999	1.199	-.030	.063	-.574	.999	-.058	-.012
.250	-.974	1.186	-.105	.153	-.621	1.020	-.111	-.015
.300	-.954	1.177	-.139	.242	-.674	1.044	-.039	-.088
.350	-.930	1.165	-.507	.848	-.690	1.051	-.149	-.191
.400	-.873	1.137	-2.026	2.922	-.727	1.068	-.182	-.189
.450	-.830	1.117	-2.427	-.632	-.719	1.064	.968	-.052
.500	-.795	1.100	-1.356	-4.594	-.582	1.003	.159	.015
.550	-.761	1.084	2.920	-3.489	-.374	.912	.012	.044
.600	-.674	1.044	2.237	2.641	-.202	.839	.031	.001
.650	-.510	.971	.267	.514	-.056	.778	.067	.029
.700	-.371	.911	-.110	.211	.078	.721	.105	.012
.725	-.295	.879	-.182	.029	.131	.699	-.016	-.010
.760	-.239	.855	-.202	-.082	.202	.669	.092	.003
.775	-.206	.841	-.339	-.126	.227	.658	.076	-.015
.800	-.137	.812	-.250	-.159	.267	.641	.058	-.009
.850	-.021	.763	-.062	-.020	.330	.613	.008	.000
.900	.069	.725	-.143	.196	.369	.596	-.001	.020
.950	.135	.697	-.237	.257	.372	.595	.040	.014

TEST DATA	MODEL DATA		OVERALL DATA		STEADY	UNSTEADY
	RZ	IM	RZ	IM		
MEETRUNNR.	149	ALPHA	.85 DEG.			
MACH	.754	DELTA	.02 DEG.	NORMAL FORCE CL	.390	.037 .007
Q (PA)	27528	AMPL.	.95 DEG.	MOMENT(1/4C) CH	.076	-.006 .013
RE	2.3386	FREQ.	30.0 RZ	FLAP FORCE RC	.0739	.0033 -.0034
MARH	2	RFREQ	.067	WINGE MOMENT NC	.0074	-.0013 -.0021
IDENTNR.	6					

TABLE 4.22

SECOND HARMONIC TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	UPPERSIDE				LOWERSIDE			
	CP+	M+	CPRE+	CPIH+	CP-	M-	CPRE-	CPIH-
.010	.329	.614	-.022	-.028	.313	.621	.025	-.057
.030	-.955	1.176	-.032	.091	-.286	.875	.068	-.031
.050	-1.014	1.207	-.008	.046	-.452	.946	.023	-.030
.100	-1.091	1.247	-.000	.024	-.511	.972	.023	.005
.150	-1.036	1.217	-.017	.030	-.530	.980	.038	-.003
.200	-1.001	1.201	.001	.082	-.579	1.000	.023	-.001
.250	-.972	1.186	-.007	.043	-.620	1.020	.026	.018
.300	-.933	1.173	-.003	.118	-.671	1.043	.031	.002
.350	-.928	1.166	-.139	.217	-.689	1.051	.087	.060
.400	-.870	1.136	-1.110	1.159	-.727	1.068	.152	.107
.450	-.829	1.116	.302	-.2389	-.719	1.065	.338	-.033
.500	-.803	1.103	1.079	-.719	-.382	1.003	.047	.135
.550	-.793	1.082	-.963	2.435	-.373	.912	.004	.108
.600	-.671	1.043	-.322	-.1877	-.201	.839	.021	.106
.650	-.511	.972	-.117	-.489	-.057	.779	.006	.111
.700	-.371	.911	.001	-.211	.078	.722	.020	.112
.725	-.295	.879	-.004	-.119	.132	.699	.017	.113
.760	-.239	.855	-.060	.062	.201	.669	.011	.102
.775	-.206	.841	-.093	-.015	.228	.658	.011	.114
.800	-.136	.812	.034	-.009	.248	.641	.026	.100
.850	-.022	.764	-.023	-.058	.330	.613	.011	.093
.900	.069	.725	-.103	-.355	.389	.596	-.006	.054
.950	.135	.697	-.237	-.150	.372	.595	-.028	.037

TEST DATA	MODEL DATA		OVERALL DATA		STEADY	UNSTEADY
	RZ	IM	RZ	IM		
MEETRUNNR.	150	ALPHA	.85 DEG.			
MACH	.755	DELTA	.02 DEG.	NORMAL FORCE CL	.390	.031 .043
Q (PA)	27537	AMPL.	.95 DEG.	MOMENT(1/4C) CH	.076	.011 .044
RE	2.3386	FREQ.	30.0 RZ	FLAP FORCE RC	.0739	-.0005 .0117
MARH	3	RFREQ	.067	WINGE MOMENT NC	.0074	.0001 .0029
IDENTNR.	6					

TABLE 4.23

FUNDAMENTAL FREQUENCY TEST DATA NLR 7301 WITH OSCILLATING FLAP

X/C	UPPERSIDE				LOWERSIDE				CPFM-
	CP+	M+	CPRE+	CPIM+	CP-	M-	CPRE-		
.010	.334	.613	.154	-.688	.316	.621	-.050	1.042	
.030	-.946	1.177	.465	-1.072	-.285	.877	-1.841	1.397	
.050	-1.006	1.207	.190	-.692	-.452	.942	-.922	.616	
.100	-1.083	1.247	.122	-.703	-.511	.974	-1.242	.505	
.150	-1.026	1.217	.099	-.809	-.530	.982	-1.539	.244	
.200	-.993	1.200	-.103	-.925	-.573	1.001	-1.835	.147	
.250	-.966	1.187	-.332	-1.094	-.616	1.021	-2.146	.784	
.300	-.945	1.176	-.560	-1.161	-.670	1.043	-2.016	-1.425	
.350	-.925	1.166	-.959	-1.320	-.680	1.050	-1.836	-3.774	
.400	-.896	1.152	-1.049	-1.833	-.712	1.065	-.422	-5.230	
.450	-.788	1.100	-.505	-5.948	-.733	1.074	5.262	-6.610	
.500	-.695	1.057	7.227	-1.821	-.572	1.001	6.297	-1.647	
.550	-.687	1.053	7.596	3.866	-.365	.911	4.839	.422	
.600	-.661	1.041	.002	10.300	-.199	.840	3.637	.954	
.650	-.543	.989	-7.826	7.013	-.057	.781	3.378	.856	
.700	-.369	.913	-6.432	.319	.070	.727	3.207	.975	
.725	-.299	.883	-5.431	-.381	.122	.705	2.887	1.038	
.760	-.229	.853	-5.075	-1.432	.196	.673	2.809	1.223	
.775	-.190	.840	-4.991	-1.792	.222	.662	2.675	1.415	
.800	-.132	.812	-3.286	-2.022	.263	.644	2.336	1.535	
.850	-.020	.765	-1.446	-1.301	.326	.617	1.637	1.782	
.900	.070	.727	-1.047	-.845	.364	.600	1.301	1.543	
.950	.135	.699	-1.397	-.402	.367	.598	.711	1.049	

TEST DATA	MODEL DATA	OVERALL DATA	STEADY	UNSTEADY
MERTRUNNR. 162	ALPHA .83 DEG.			
MACH .755	DELTA -.01 DEG.			
Q (PA) 27637	AMPL. .90 DEG.			
RE 2.23E6	FREQ. 200.0 Hz	NORMAL FORCE CL	.339	.611
HARM 1	RFREQ .445	MOMENT(1/4C) CM	.073	.740
IDENTNR. 6		FLAP FORCE RC	.0763	-.024
		WINGE MOMENT RC	.0073	.2801
				.1832
				.0340

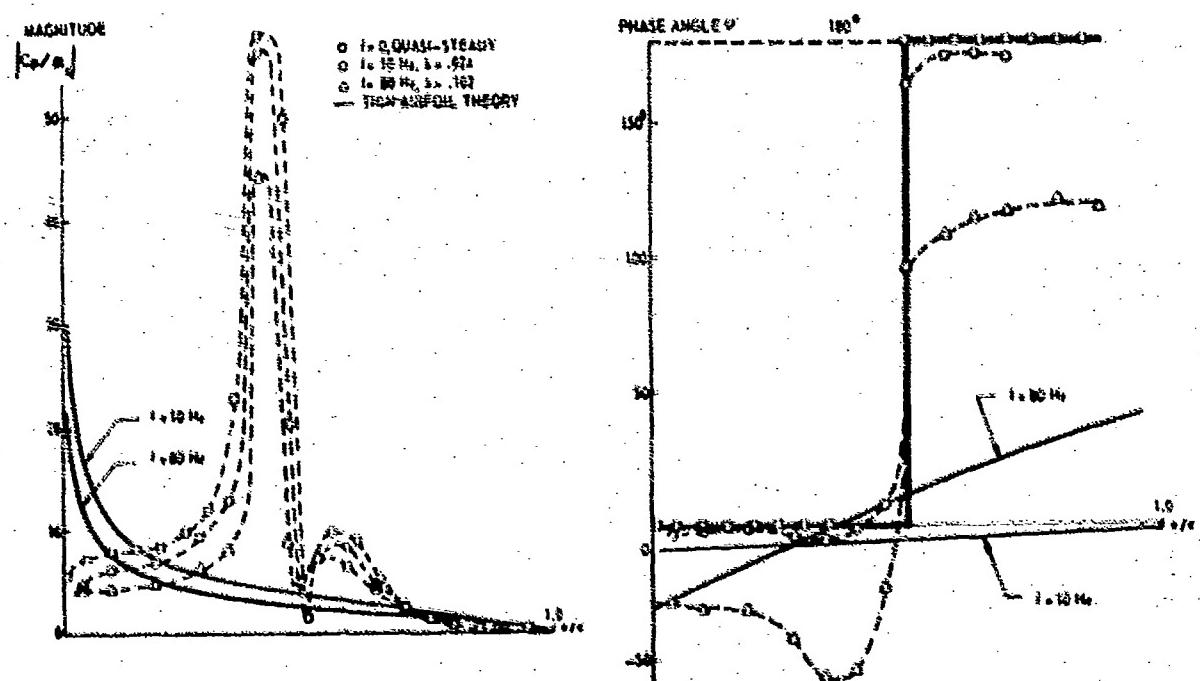
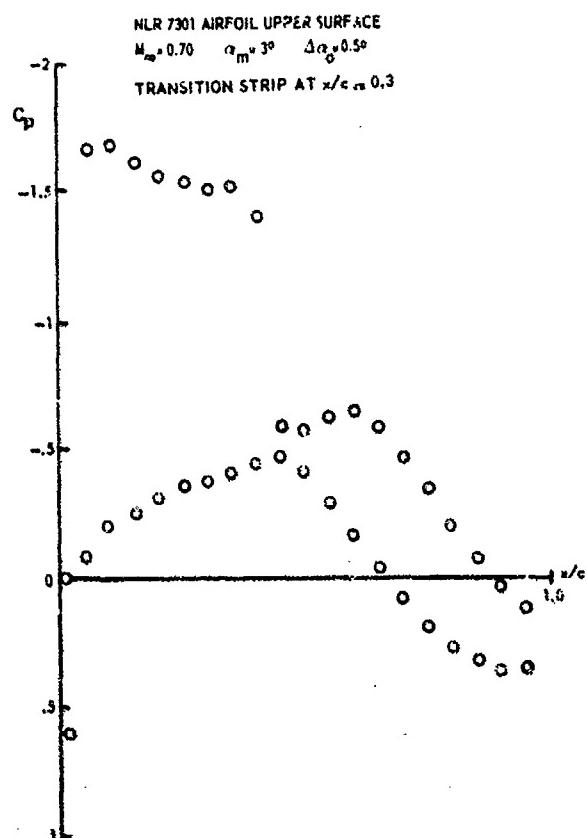


Fig. 4.1 Effect of shock wave on the unsteady pressure distributions; pitching oscillation

NLR 7301 AIRFOIL, UPPER SURFACE
 $M_\infty = 0.745 \quad \alpha_m = 0.85^\circ \quad \Delta\alpha_0 = 0.5^\circ$

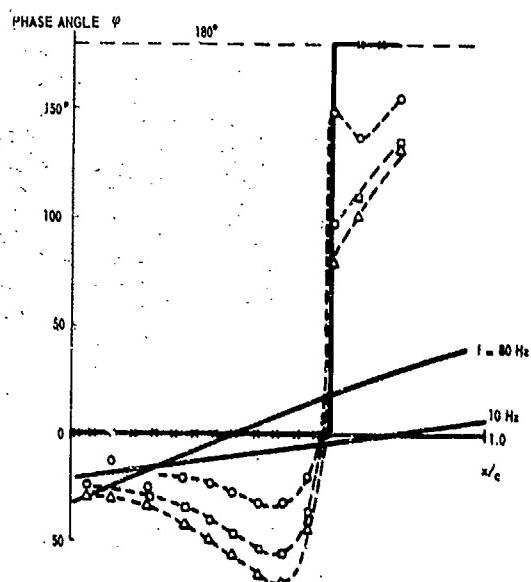
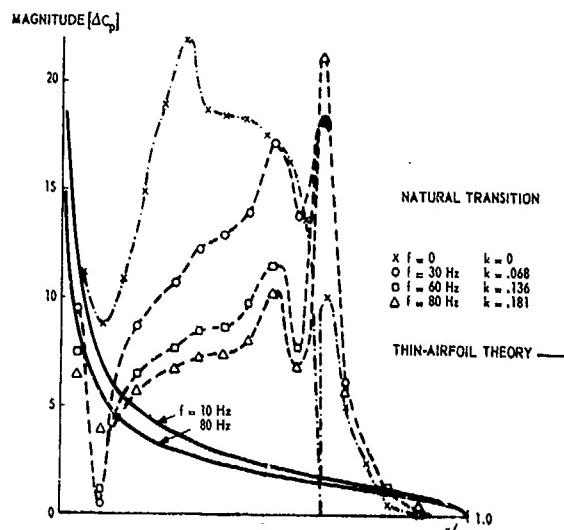
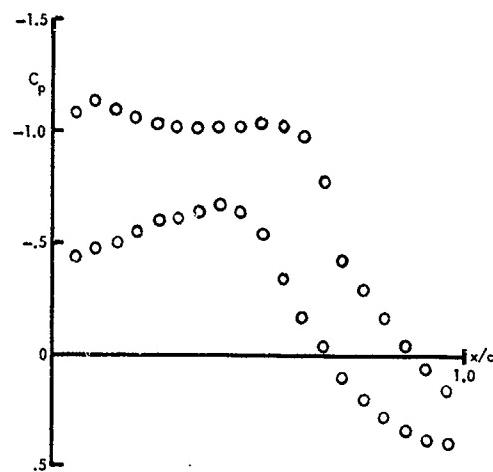


Fig. 4.2 Unsteady pressure distributions for the "shock-free" design point; pitching oscillation

NLR 7301 AIRFOIL
 $M_\infty = 0.70 \quad \alpha_m = 0.3^\circ \quad \Delta\alpha_0 = 0.5^\circ$

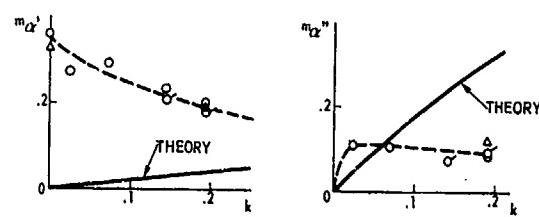
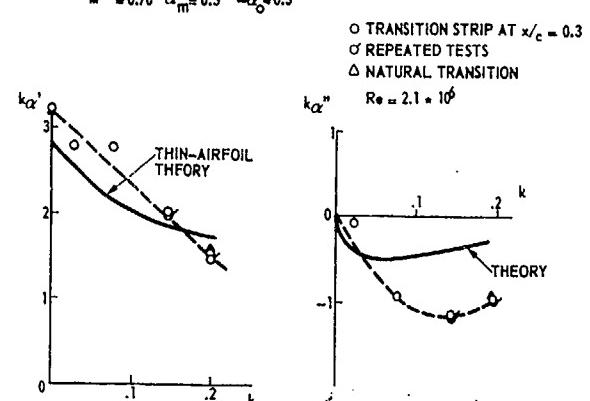


Fig. 4.3 Unsteady normal-force and moment coefficients as a function of frequency in transonic flow with a well-developed shock wave; pitching oscillation

NLR 7301 AIRFOIL
 $M_\infty = 0.745 \quad \alpha_m = 0.85^\circ \quad \Delta\alpha_0 = 0.5^\circ$

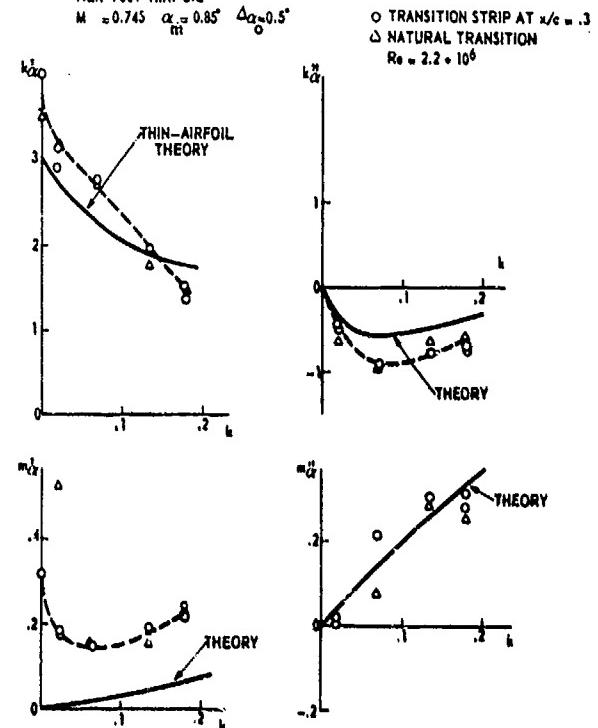
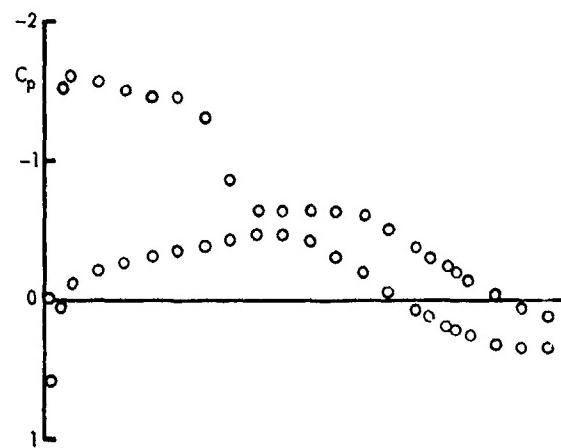


Fig. 4.4 Unsteady normal-force and moment coefficients as a function of frequency for the "shock-free" design point; pitching oscillation

NLR 7301 AIRFOIL UPPER SURFACE
 $M=0.7, \alpha_m=3^\circ, \delta_m=0^\circ, \delta_o=1^\circ$
 TRANSITION STRIP AT $x/c=0.3$



NLR 7301 AIRFOIL UPPER SURFACE
 $M=0.754, \alpha_m=0.85^\circ, \delta_m=0^\circ, \delta_o=1^\circ$
 NATURAL TRANSITION

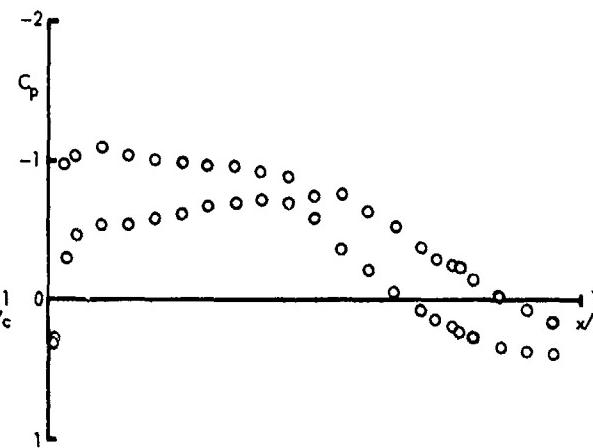
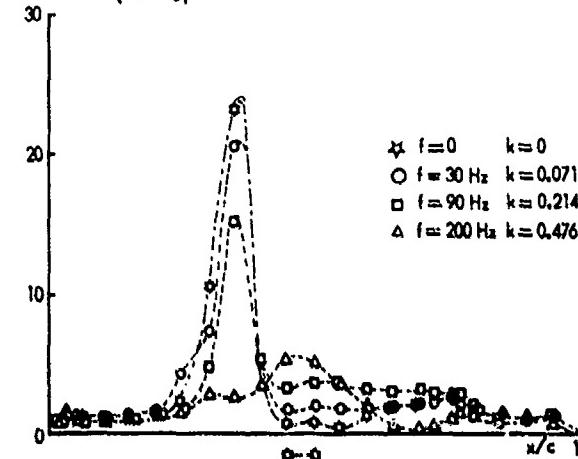
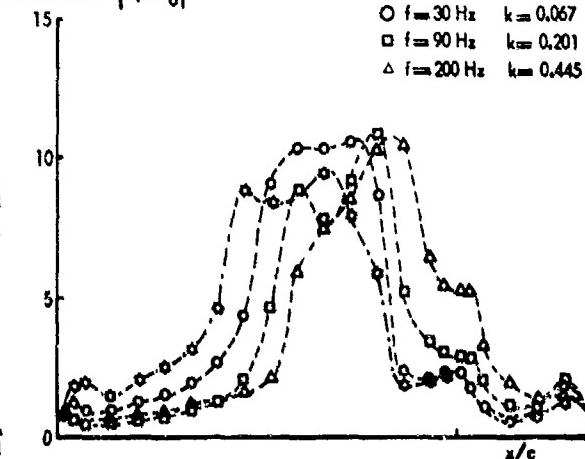
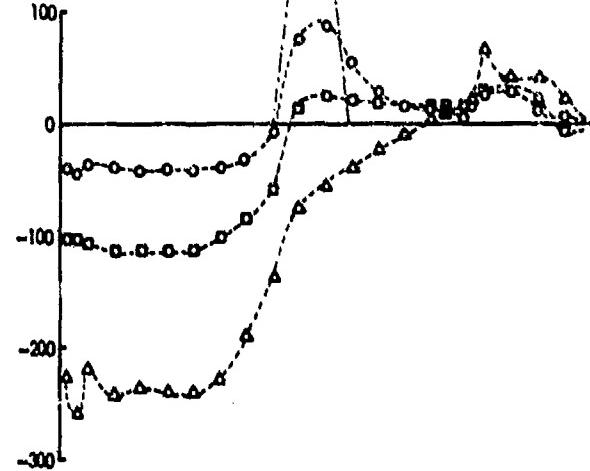
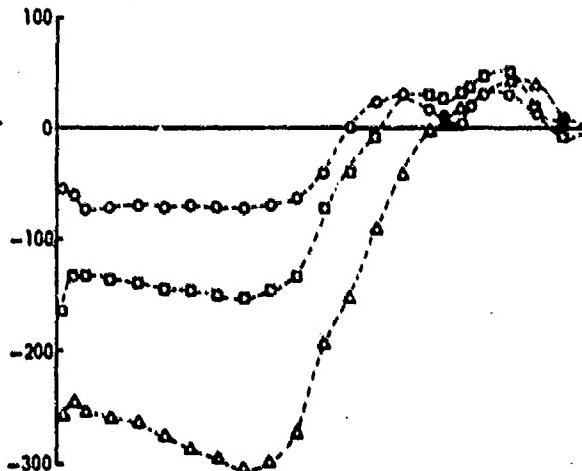
MAGNITUDE $|C_p/\delta_0|$ MAGNITUDE $|C_p/\delta_0|$ PHASE ANGLE ϕ PHASE ANGLE ϕ 

Fig. 4.5 Effect of shock wave on the unsteady pressure distributions: flap oscillation

Fig. 4.6 Unsteady pressure distributions for the "shock-free" design point; flap oscillation

NLR 7301 AIRFOIL
 $\delta_m = 0^\circ$ $\delta_0 \approx 1^\circ$ $R_e = 2.2 \times 10^6$
 $M = 0.750$ $\alpha_m = 0.07^\circ$ $M = 0.756$ $\alpha_m = 1.2^\circ$
 Δ NATURAL TRANSITION ; $M = 0.754$, $\alpha_m = 0.85^\circ$

NLR 7301 AIRFOIL
 $\delta_m = -2^\circ$ $\delta_0 = 0^\circ$ $\delta_0 = 1^\circ$ $R_e = 2.1 \times 10^6$
 Δ NATURAL TRANSITION
 \circ TRANSITION STRIP AT $X/C = 0.3$
 ∇ TRANSITION STRIP AT $X/C = 0.07$
 Δ NATURAL TRANSITION

NLR 7301 AIRFOIL
 $\delta_m = 0^\circ$ $\delta_0 \approx 1^\circ$ $R_e = 2.2 \times 10^6$
 \circ TRANSITION STRIP AT $X/C = 0.3$; $M = 0.754$, $\alpha_m = 1^\circ$
 ∇ TRANSITION STRIP AT $X/C = 0.07$; $M = 0.756$, $\alpha_m = 1.2^\circ$
 Δ NATURAL TRANSITION ; $M = 0.754$, $\alpha_m = 0.85^\circ$

NLR 7301 AIRFOIL
 $\delta_m = 0^\circ$ $\delta_0 \approx 1^\circ$ $R_e = 2.2 \times 10^6$
 \circ TRANSITION STRIP AT $X/C = 0.3$; $M = 0.754$, $\alpha_m = 1^\circ$
 ∇ TRANSITION STRIP AT $X/C = 0.07$; $M = 0.756$, $\alpha_m = 1.2^\circ$
 Δ NATURAL TRANSITION ; $M = 0.754$, $\alpha_m = 0.85^\circ$

NLR 7301 AIRFOIL
 $\delta_m = 0^\circ$ $\delta_0 \approx 1^\circ$ $R_e = 2.2 \times 10^6$
 \circ TRANSITION STRIP AT $X/C = 0.3$; $M = 0.754$, $\alpha_m = 1^\circ$
 ∇ TRANSITION STRIP AT $X/C = 0.07$; $M = 0.756$, $\alpha_m = 1.2^\circ$
 Δ NATURAL TRANSITION ; $M = 0.754$, $\alpha_m = 0.85^\circ$

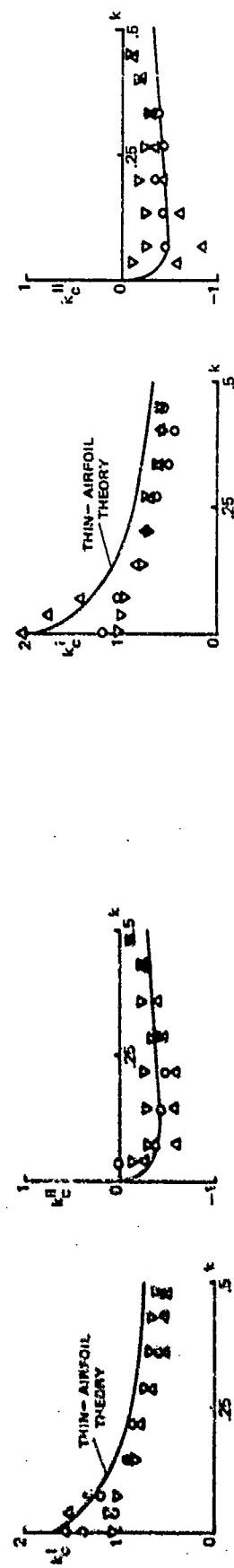


FIG. 4.7 Unsteady aerodynamic coefficients as functions of frequency in transonic flow with a well-developed shock wave; flap oscillation

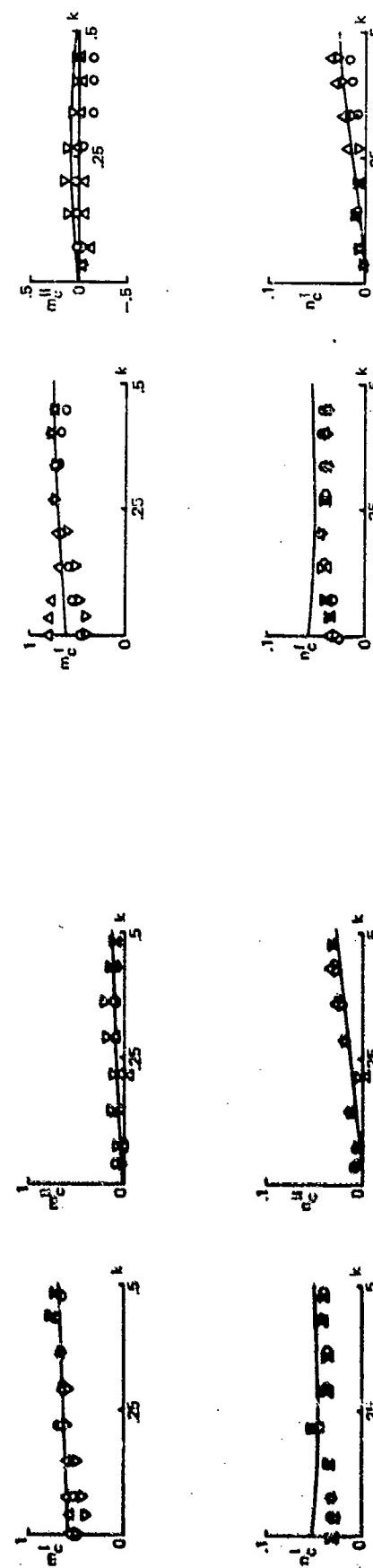


FIG. 4.8 Unsteady aerodynamic coefficients as functions of frequency for best "shock-free" steady flow; flap oscillation

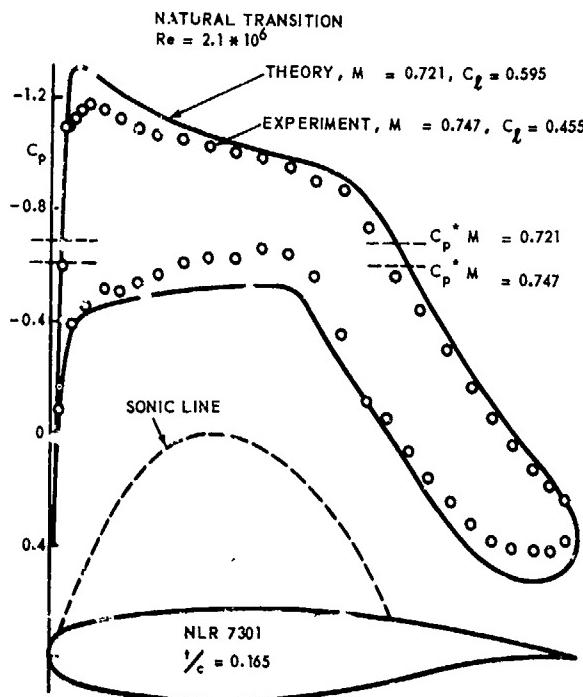
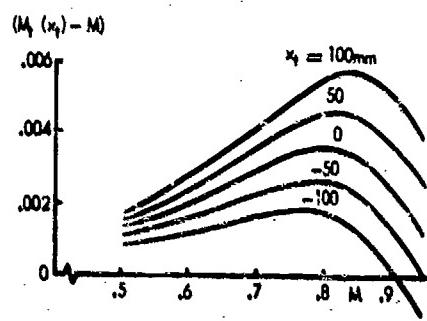


Fig. 4.9 Theoretical and experimental "shock-free" pressure distributions of the NLR 7301 airfoil (free transition)



M_x = WIND TUNNEL MACH NUMBER
x_t = DOWNSTREAM COORDINATE ALONG TEST SECTION CENTRE LINE, MEASURED FROM MODEL MIDCHORD

Fig. 4.11 Mach number distribution in NLR Pilot Tunnel test section

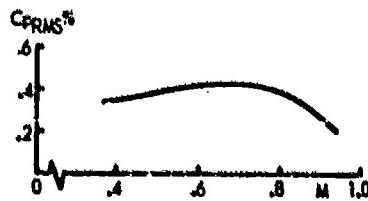


Fig. 4.12 Noise level in NLR Pilot Tunnel test section

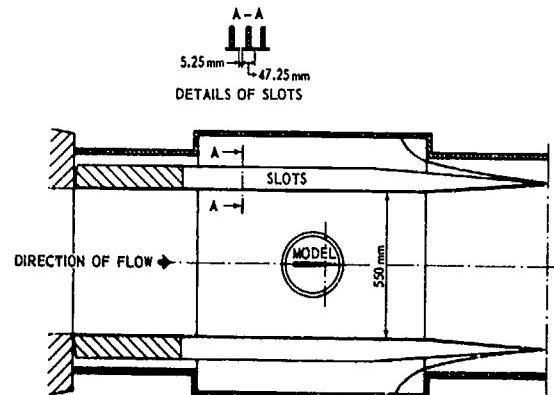


Fig. 4.10 Transonic test section of the NLR Pilot Tunnel

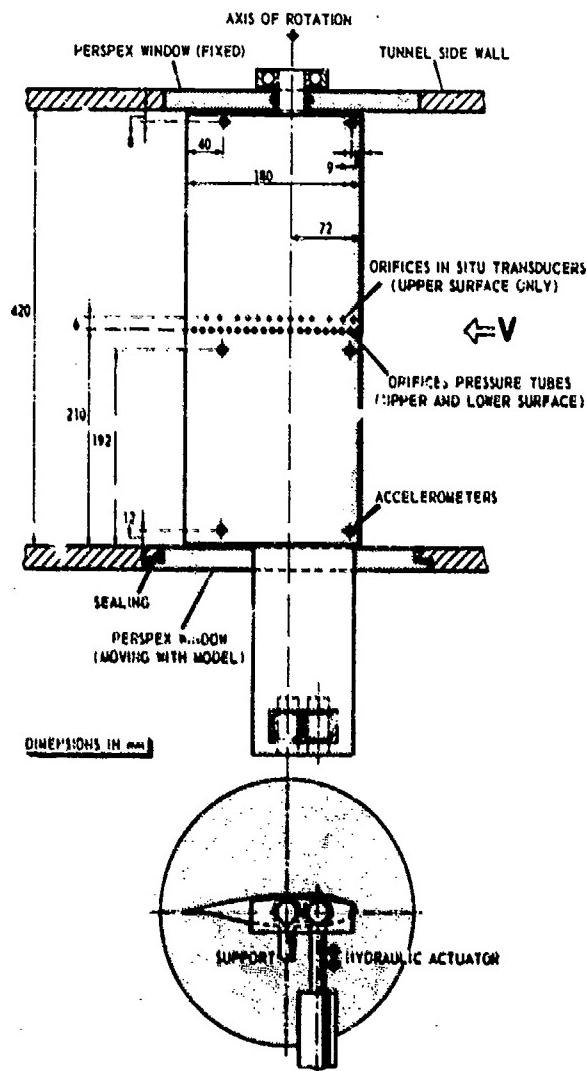
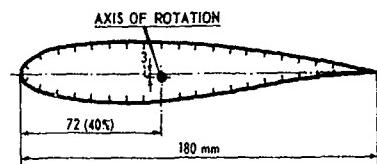


Fig. 4.13 Test set-up and instrumentation of the NLR 7301 airfoil (Conf. A)



PRESSURE ORIFICES TUBING SYSTEM (BOTH UPPER AND LOWER SURFACE)		IN SITU TRANSDUCERS (UPPER SURFACE ONLY)	
No. 1	$x/c = .01$	No. 11	$x/c = .50$
2	.05	12	.55
3	.10	13	.60
4	.15	14	.65
5	.20	15	.70
6	.25	16	.75
7	.30	17	.80
8	.35	18	.85
9	.40	19	.90
10	.45	20	.95

Fig. 4.14 Location of pressure orifices of the NLR 7301 airfoil (Conf. A)

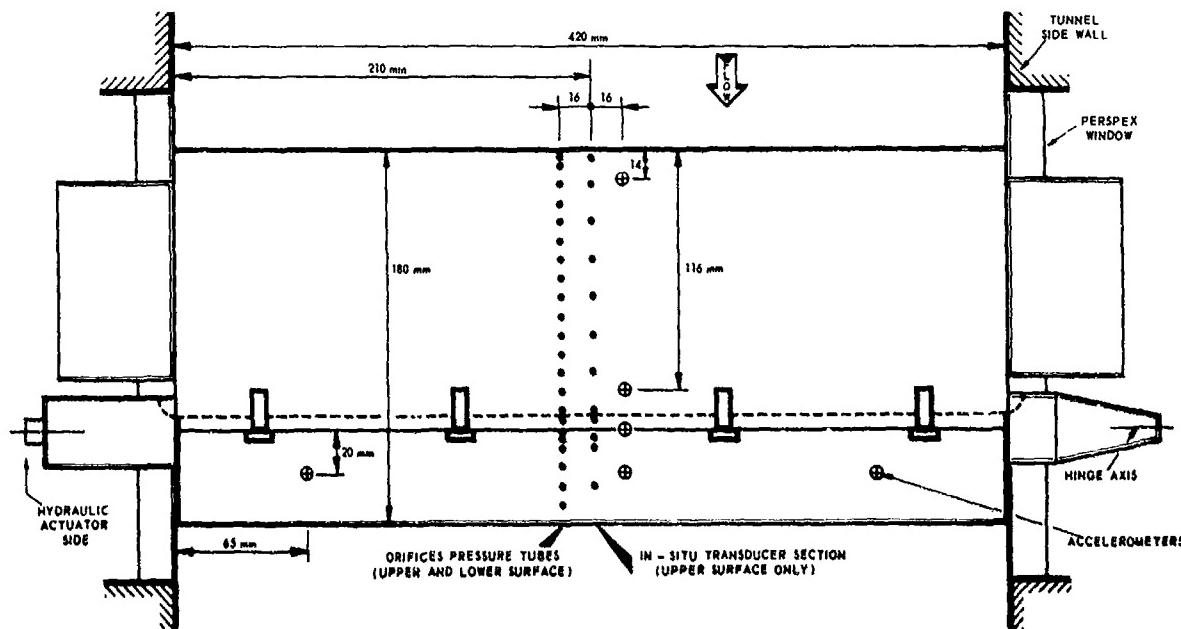
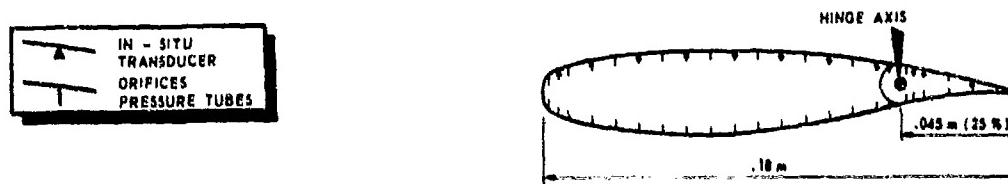


Fig. 4.15 Test set-up and instrumentation of the NLR 7301 airfoil with control surface (Conf. B)



PRESSURE ORIFICES TUBING SYSTEM (both upper and lower surface)		IN SITU TRANSDUCERS (upper surface only)	
no. 1	$x/c = .01$	no. 13	$x/c = .55$
2	.03	14	.60
3	.05	15	.65
4	.10	16	.70
5	.15	17	.725
6	.20	18	.76
7	.25	19	.775
8	.30	20	.8
9	.35	21	.85
10	.40	22	.90
11	.45	23	.95
12	.50		

Fig. 4.16 Location of pressure orifices of the NLR 7301 airfoil with control surface (Conf. B)

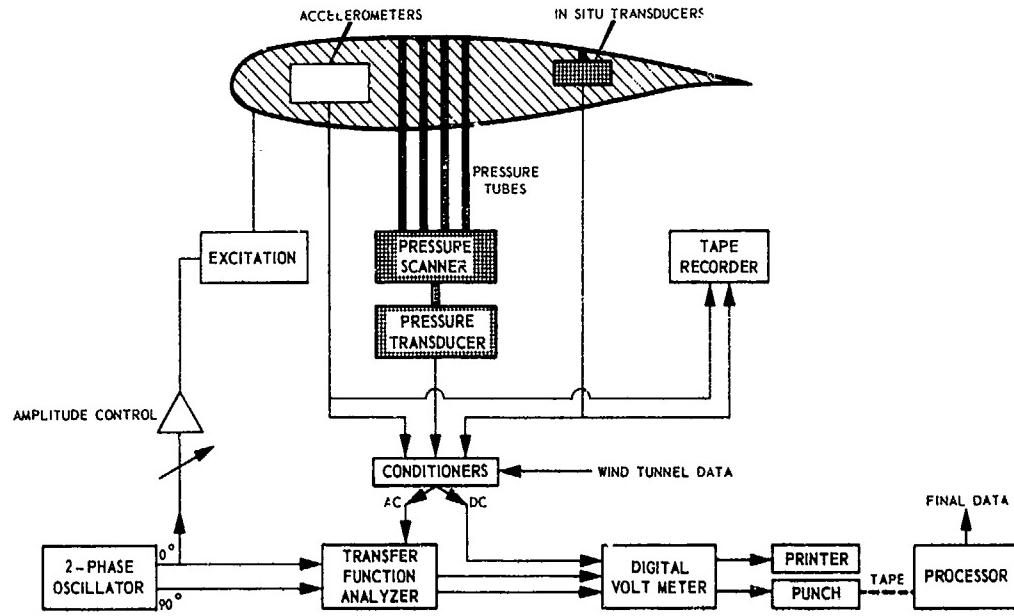


Fig. 4.17 Block diagram of measuring equipment (Conf. A). Similar equipment essentially for Conf. B

DATA SET 5

NLR 7301 SUPERCRITICAL AIRFOIL OSCILLATORY PITCHING

by

Sanford S. Davis, NASA Ames

INTRODUCTION AND DISCUSSION

Test data on the NLR 7301 supercritical airfoil were acquired concurrently with the NACA 64A010 data previously described in Data Set 2. The purpose of this Data Set is to tabulate numerical data from those tests that can be associated with the AGARD CT Cases and to present an overview of certain parametric data trends. The test arrangement for this airfoil is the same as that described in Data Set 2 and is reproduced in Fig. 5-1.

Users of these data should be aware of some differences in the methods of specifying the geometry of the NLR supercritical airfoil whose general properties are described in Ref. 5.1. The differences between the original coordinates which, as given by Table 4.1 of Data Set 4, locate the sharp trailing edge at $X/C \approx 1.015$, and the transformed coordinates given by Table 5 of Ref. 5.2 are explained in Data Set 4. However, the coordinates used to construct the model of the present tests were derived from the original specification in yet another manner. As for the model of Data Set 4, the physical model of the present tests was obtained by truncating the trailing edge of the original design at $X/C = 1.0$. But unlike the model of Data Set 4, the chord was redefined as the line connecting the nose of the airfoil with the bisection point of the truncated trailing edge. In effect, the design shape of the present model is the same as that of the NLR model of Data Set 4 and, apart from the trailing-edge truncation, is the same shape as that defined in Ref. 5.2 for the AGARD Computation Tests. However, because of the method of defining the chord line, there is a slight difference in the definitions of incidence. The sensitivity of the computed flow to the minor variations listed above is not expected to be a major problem, but the analyst should be aware of their existence.

The data base for this airfoil is presented in Table 5.1 and consists of 95 parametric combinations. The data subset corresponding to a pitching axis at 0.40c is listed in Table 5.2. The AGARD CT Cases advocated in Ref. 5.2 do not precisely match the current data set. In Table 5.3 tests from the current series are correlated with the AGARD CT Cases by matching similar mean flow conditions. The three flow regimes selected are: (1) a subcritical Mach number, (2) an off-design flow condition with a strong shock wave, and (3) the supercritical design point.

In these tests lower surface unsteady pressure data were sacrificed for the sake of increased upper surface resolution. For this reason lift and moment data are not available. In Tables 5.4 to 5.23 first harmonic upper surface and steady pressure data for the 20 runs identified in Table 5.3 are reproduced from Ref. 5.3. Complete instantaneous pressure distributions are presented in Tables 5.24 and 5.25 for the high Reynolds number data associated with AGARD CT Cases 6 and 8.

In Figs. 5.2 to 5.10 the steady pressure distributions are shown, and certain parametric trends are presented concerning the upper surface fundamental frequency pressure distribution. The picture that emerges is one of a complex dynamic flow pattern that is sensitive to many parameters. More coordinated research needs to be done before definitive data suitable for aeroelastic applications become available. Other supercritical airfoil data may be found in Data Set 4 and the references cited herein.

The effect of varying the frequency parameter alone is shown in Figs. 5.2 to 5.4. Figure 5.2 depicts a subsonic flow condition where the classical thin airfoil theory should remain valid. The general trend confirms the flat plate theory -- decreasing real portion and increasing imaginary portion as frequency increases -- except for the curious dip just upstream of the 0.2c station. This phenomenon is consistent with the full time-histories and comparison with other data (see Fig. 5.8) will show that it is likely a viscous effect. (The dip in the mean pressure distribution at approximately 0.4c was traced to a surface wave in the airfoil contour.) In Fig. 5.3 the Mach number and mean angle of attack are increased enough to induce a strong shock wave with possible separation at the trailing edge. The pressure distributions are dramatically different at the two frequencies shown. An especially important point, one that cannot be stressed too strongly, is that the variation of unsteady lift and moment (not shown) may show erratic trends with frequency because of the balancing of positive and negative lobes in the pressure distributions. More examples of this phenomenon are described in Refs. 5.4, 5.5 and 5.6. Figure 5.4 completes this series by showing the variation of unsteady pressure distributions with frequency at the supercritical design point. Unlike conventional airfoils, a broad, high level of unsteady loading persists over the forward portion of the airfoil at low frequencies. The net effect is larger unsteady loads on supercritical airfoils than that usually found on conventional airfoils.

The next series of three figures shows data trends with varying oscillation amplitude. Figure 5.5 indicates that the normalized oscillatory pressure distribution remains relatively invariant in subsonic flow. This is a good indication of a linear response over the range indicated. Figure 5.6 shows only minor departures from linearity up to $a_0 = 1^\circ$, even with a strong shock wave present. Figure 5.7 shows progressive changes with amplitude a_0 at the supercritical design point that cast doubt on the linearity assumption. Whether or not the response curves are "sufficiently linear" must await aeroelastic sensitivity calculations.

The next series of figures shows the scale effect on the steady and oscillatory pressures. In this connection, it should be noted that the model did not have a boundary layer transition trip. The trends on the unsteady pressures are disconcerting because the Reynolds number seems to be an important parameter, especially at and near the supercritical design point. In Fig. 5.8 the major effect of increasing Reynolds number is to induce the leading edge dip in the unsteady pressure distribution. In Fig. 5.9 the first harmonic pressures aft of the shock wave seem to be most affected. This may cause major changes in the unsteady moment as well as the lift. In Fig. 5.10 the unsteady loading at the design point seems to be significantly affected by changing the Reynolds number. At this stage it is impossible to trace the root causes of the relatively severe scale effects on a supercritical airfoil (see Ref. 5.3 for other data). A computational model that includes all of the significant physical effects is surely necessary.

The higher harmonic content of the unsteady pressure distributions is also significantly affected by flow condition. Figure 5.11 shows the complete space-time pressure distributions at the supercritical design point (CT Cases 6 and 8) when $Re = 11.5 \times 10^6$. The harmonic distortion is significantly affected by the frequency parameter, but is concentrated near the end of the region where the steady flow is supersonic. General trends should not be deduced from this special choice of parameters, just as harmonic distortion in the overall loads cannot be inferred from the harmonic content of the pressure distributions themselves (Ref. 5.4).

1	AIRFOIL	
1.1	Designation	NLR
1.2	Type of airfoil	Supercritical - $t/c = 16.5\%$
1.3	Geometry	Table 2 of Ref. 5.3
1.4	Design condition	$M = 0.721, \alpha_m = -0.19^\circ$ (theoretical, quoted in Ref. 5.2)
1.5	Additional remarks	
1.6	References on airfoil	See Introduction of this Data Set.
2	MODEL GEOMETRY	
2.1	Chord length	0.50 m (19.685 in.)
2.2	Span	1.35 m (53.2 in.)
2.3	Actual model coordinates and accuracy of measurement	Ref. 5.3
2.4	Flap, hinge and gap details	None
2.5	Additional remarks	Model mounted between splitter plates - see Fig. 5.1
2.6	References on model	Ref. 5.3
3	WIND TUNNEL	
3.1	Designation	NASA Ames 11- x 11-Foot Transonic Wind Tunnel
3.2	Type of tunnel	Closed return, variable density
3.3	Test section dimensions	3.35 x 3.35 x 6.7 m (11 x 11 x 22 ft.)
3.4	Type of roof and floor	Baffled slot
3.5	Type of side walls	Same as 3.4
3.6	Ventilation geometry	1.78 cm (0.7 in.) slots, 24.4 cm (9.63 in.) slats. Open area ratio ~ 8% between splitters.
3.7	Thickness of side wall boundary layer	Very thin due to splitters
3.8	Thickness of boundary layers at roof and floor	Approx. 7.6 cm (3 in.)
3.9	Method or measuring Mach number	Static tape and splitters, see Ref. 5.6.
3.10	Uniformity of Mach number over test section	±0.002
3.11	Sources and levels of noise or turbulence in empty tunnel	Not investigated
3.12	Tunnel resonances	None noted
3.13	Additional remarks	
3.14	References on tunnel	Ref. 5.3
4	MODEL MOTION	
4.1	Mode of applied motion	Pitching about nominal 0.40c, also plunging
4.2	Range of amplitude	±0-2 deg; ±1 cm
4.3	Range of frequency	0-60 Hz
4.4	Method of application	Pour graphite epoxy push-pull rods with differential motion of forward and aft pair, see Fig. 5.1.

4	MODEL MOTION (Continued)	
4.5	Purity of applied motion	Pure sinusoids
4.6	Natural frequencies and normal modes of model	Lowest mode: torsion at 60 Hz
4.7	Static or dynamic elastic distortion during tests	Not measured
4.8	Additional remarks	
5	TEST CONDITIONS	
5.1	Tunnel height/model chord ratio	3.35 m/0.50 m = 6.7
5.2	Tunnel width/model chord ratio	1.35 m/0.50 m = 2.7 (between splitter plates)
5.3	Range of Mach number	0.40 - 0.85
5.4	Range of tunnel total pressure	50 kN/m ² - 225 kN/m ² (0.5-2.25 ATM)
5.5	Range of tunnel total temperature	290 K - 320 K
5.6	Range of model steady, or mean, incidence	0 - 2.5 deg.
5.7	Definition of model incidence	Chord line relative to wind tunnel.
5.8	Position of transition, if free	Transition was observed using a sublimating material at two flow conditions. At $M = 0.453$, $\alpha_m = 0.57^\circ$, $Re = 4.5 \times 10^6$ a definite transition point was not observed. At $M = 0.708$, $\alpha_m = 0.58^\circ$, $Re = 6.2 \times 10^6$, transition occurred at $x/c \sim 0.10$.
5.9	Position and type of trip, if transition fixed	
5.10	For mixed flow, position of sonic boundary in relation to roof and floor	Not measured
5.11	Flow instabilities during tests	--
5.12	Additional remarks	--
5.13	References describing tests	--
6	MEASUREMENTS AND OBSERVATIONS	
6.1	Steady pressures for the mean conditions	
6.2	Steady pressures for small changes from the mean conditions	
6.3	Quasi-steady pressures	
6.4	Unsteady pressures	
6.5	Steady forces for the mean conditions	measured directly
6.6	Steady forces for small changes from the mean conditions	integrated pressures
6.7	Quasi-steady forces	measured directly
6.8	Unsteady forces	integrated pressures
6.9	Measurement of actual motion at points on model	measured directly
6.10	Observation or measurement of boundary layer properties	integrated pressures
6.11	Visualization of surface flow	measured directly
6.12	Visualization of shockwave movements	integrated pressures
6.13	Additional remarks	measured directly
7	INSTRUMENTATION	
7.1	Steady pressures	
7.1.1	Position of orifices spanwise and chordwise	Mid-span 29 upper, 12 lower. (May vary with data, see Table 5.4 for locations.)
7.1.2	Type of measuring system	Pneumatic
7.2	Unsteady pressures	
7.2.1	Position of orifices spanwise and chordwise	Mid-span, 29 upper, none on lower. (May vary with data, see Table 5.4 for locations.)
7.2.2	Diameter of orifices	0.102 cm (0.040 in.)

7 INSTRUMENTATION (Continued)

7.2.3	Type of measuring system	strain-gauge-type miniature pressure transducers installed close to orifice with minimum cavities.
7.2.4	Type of transducers	Kulite model XQOL-7A-093.
7.2.5	Principle and accuracy of calibration	On-line calibrations. Up to 2% change in static sensitivity before and after run allowed.
7.3	Model motion	
7.3.1	Method of measurement	Motion of four push-pull rods with LVDT (reactive-type) transducers. Phase synchronism checked with wing-mounted accelerometers.
7.3.2	Accuracy	~ 1%
7.4	Processing of unsteady measurements	
7.4.1	Method of acquiring and processing measurements	Real-time digitization with on-line calibration and diagnostics. Signal averaging over approx. 100 cycles to suppress random noise (if present). Variable sampling time adjusted to yield 60 data points per cycle.
7.4.2	Type of analysis	On-line processing for frequency content of pressure distributions and comparisons with linear theory and other data.
7.4.3	Unsteady pressure quantities obtained and accuracies achieved	Signal averaged (essentially instantaneous) pressured distributions. Harmonic analysis of pressure distributions.
7.4.4	Method of integration to obtain forces	Numerical quadratures (see Appendix A of Ref. 5.3).
7.5	Additional remarks	
7.6	References on techniques	Ref. 5.6

8 DATA PRESENTATION

8.1	Test cases for which data could be made available	Table 5.1
8.2	Test cases for which data are included in this document	Table 5.3
8.3	Steady pressures	Tables 5.4 to 5.23
8.4	Quasi-steady or steady perturbation pressures	Not available
8.5	Unsteady pressures	Tables 5.4 to 5.25
8.6	Steady forces or moments	Not available
8.7	Quasi-steady or steady perturbation forces	Not available
8.8	Unsteady forces and moments	Not available
8.9	Other forms in which data could be made available if required	Magnetic tape
8.10	References giving other presentations of data	Refs. 5.3 to 5.5

9 COMMENTS ON DATA

9.1	Accuracy	
9.1.1	Mach number	±0.002
9.1.2	Steady incidence	±0.05 deg
9.1.3	Reduced frequency	±0.005
9.1.4	Steady pressure coefficients	1%
9.1.5	Steady pressure derivatives	N/A
9.1.6	Unsteady pressure coefficients	2%
9.2	Sensitivity to small changes of parameter	No evidence of undue sensitivity
9.3	Spanwise variations	Probably small
9.4	Nonlinearities	Depends on parametric conditions
9.5	Influence of tunnel total pressure	Minimal on model distortion, probably all Reynolds number effect.
9.6	Wall interference corrections	No corrections made
9.7	Other relevant tests on same model	None

9 COMMENTS ON DATA (Continued)

- 9.8 Relevant tests on other models of nominally the *same* aerofoil. See Data Set 4 of this Compendium
- 9.9 Any remarks relevant to comparison between experiment and theory
- 9.10 Additional remarks
- 9.11 References on discussion of data Refs. 5.4 and 5.5

10 PERSONAL CONTACT FOR FURTHER INFORMATION

Sanford Davis, Aerodynamics Division, NASA Ames Research Center, Moffett Field, CA 94035

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NLR TR 77090U, 1977.
- 5.2 S. R. Bland AGARD Two-Dimensional Aeroelastic Configurations.
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- 5.3 S. Davis and G. Malcolm Experimental Unsteady Aerodynamics of Conventional and Supercritical Airfoils.
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- 5.4 S. Davis and G. Malcolm Unsteady Aerodynamics of Conventional and Supercritical Airfoils.
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- 5.5 S. Davis Experimental Studies of Scale Effects on Oscillating Airfoils at Transonic Speeds.
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- 5.6 S. Davis Computer/Experiment Integration for Unsteady Aerodynamic Research,
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12 NOTATION AND EXPLANATION OF TABLES*

GENERAL NOTATION

- C, c chord of airfoil, m
- DI dynamic index, data identification number
- f, FREQ frequency, Hz
- k, K reduced (nondimensional) frequency, $\frac{w_0}{2V}$
- M free-stream Mach number
- Re, RE Reynolds number (based on chord)
- t time, s
- V free-stream velocity, m/s
- x, x distance along airfoil, m
- x_0/c pitch axis position relative to leading edge
- $a(t)$ instantaneous incidence, deg ($a_m + a_o \cos \omega t$)
- a_m mean incidence, deg
- a_o oscillatory pitch amplitude, deg
- ω radian frequency, rad/s ($=2\pi f$)

TABLES 5.4 to 5.23

- ALPHA mean incidence, deg [a_m]
- PTOT total pressure, N/m² [P_t]
- PINF static pressure, N/m² [P_∞]
- QINF dynamic pressure, N/m² [q]
- CPU(CPL) steady upper (lower) surface pressure coefficient [c_p]
- CPU,A normalized complex amplitude of upper surface fundamental frequency pressure coefficient, per radian [$c_p^* / a_o + i c_l^* / a_o$]

TABLES 5.24 and 5.25

- PHASE phase angle re $a(t)_{max}$ [ωt]
- ALPHA oscillatory incidence [$a_o \cos (\omega t)$]
- CP instantaneous pressure coefficient [$c_p(t)$]

* Square-bracketed quantities indicate standard AGARD notation

TABLE 5.1. DATA BASE FOR NLR 7301 AIRFOIL

DI	M	α_m , deg	$Rex \times 10^{-6}$	Motion	f, Hz	k
115	0.453	0.57	4.47	Pitching 0.52 deg about $x_a/c = 0.394$	2.7	0.028
116	.453	.57	4.47	Pitching .50 deg about $x_a/c = .404$	5.4	.055
117	.453	.57	4.47	Pitching .48 deg about $x_a/c = .400$	10.7	.110
118	.453	.57	4.47	Pitching .49 deg about $x_a/c = .391$	21.5	.221
119	.453	.57	4.47	Pitching .49 deg about $x_a/c = .394$	32.2	.331
120	.453	.57	4.47	Pitching 1.04 deg about $x_a/c = .384$	5.4	.055
121	.453	.57	4.47	Pitching 1. deg about $x_a/c = .389$	21.5	.221
122	.453	.57	4.47	Pitching 2. deg about $x_a/c = .393$	5.4	.055
123	.453	.57	4.47	Pitching 2.00 deg about $x_a/c = .403$	21.5	.221
124	.708	.58	6.15	Pitching .52 deg about $x_a/c = .394$	3.7	.025
125	.708	.58	6.15	Pitching .50 deg about $x_a/c = .401$	7.5	.050
126	.708	.58	6.15	Pitching .49 deg about $x_a/c = .402$	29.9	.200
127	.708	.58	6.15	Pitching 1.01 deg about $x_a/c = .397$	7.5	.050
128	.708	.58	6.15	Pitching 1.00 deg about $x_a/c = .398$	29.9	.200
129	.708	.58	6.15	Pitching 2.02 deg about $x_a/c = .401$	7.5	.050
130	.708	.58	6.15	Pitching 2.00 deg about $x_a/c = .399$	29.9	.200
131	.752	.37	6.21	Pitching .51 deg about $x_a/c = .401$	4.0	.025
132	.752	.37	6.21	Pitching .50 deg about $x_a/c = .401$	8.0	.050
133	.752	.37	6.21	Pitching 0.50 deg about $x_a/c = .402$	16.0	0.100
134	.752	.37	6.21	Pitching .49 deg about $x_a/c = .403$	32.0	.200
135	.752	.37	6.21	Pitching .50 deg about $x_a/c = .403$	48.0	.300
136	.752	.37	6.21	Pitching 1.01 deg about $x_a/c = .398$	8.0	.050
137	.752	.37	6.21	Pitching 1.00 deg about $x_a/c = .397$	32.0	.200
138	.752	.37	6.21	Pitching 2.02 deg about $x_a/c = .400$	8.0	.050
139	.752	.37	6.21	Pitching 2.01 deg about $x_a/c = .399$	32.0	.200
140	.808	.36	6.26	Pitching .50 deg about $x_a/c = .402$	8.5	.050
141	.808	.36	6.26	Pitching .50 deg about $x_a/c = .407$	34.0	.199
142	.807	.36	11.78	Pitching .49 deg about $x_a/c = .404$	8.7	.050
143	.807	.36	11.78	Pitching .49 deg about $x_a/c = .398$	35.0	.200
144	.751	.37	11.48	Pitching .50 deg about $x_a/c = .403$	8.2	.050
145	.751	.37	11.48	Pitching .51 deg about $x_a/c = .399$	4.1	.025
146	.751	.37	11.48	Pitching .49 deg about $x_a/c = .400$	16.5	.100
147	.751	.37	11.48	Pitching .49 deg about $x_a/c = .401$	24.7	.150
148	.751	.37	11.48	Pitching .50 deg about $x_a/c = .403$	33.0	.201
149	.751	.37	11.48	Pitching .50 deg about $x_a/c = .400$	49.5	.301
150	.751	.37	11.48	Pitching 1.00 deg about $x_a/c = .398$	8.2	.050
151	.751	.37	11.48	Pitching 1.00 deg about $x_a/c = .400$	32.8	.200
152	.751	.37	11.48	Pitching 2.02 deg about $x_a/c = .399$	8.2	.050
153	.751	.37	11.48	Pitching 2.00 deg about $x_a/c = .402$	32.8	.200
154	.751	.37	11.48	Plunging 1.00 cm (0.395 in.)	8.2	.050
155	.751	.37	11.48	Plunging .20 cm (0.396 in.)	32.8	.200
156	.706	.59	11.22	Pitching .51 deg about $x_a/c = .400$	3.9	.025
157	.706	.59	11.22	Pitching .50 deg about $x_a/c = .402$	7.7	.050
158	.706	.59	11.22	Pitching .50 deg about $x_a/c = .399$	18.4	.099
159	.706	.59	11.22	Pitching .49 deg about $x_a/c = .401$	30.8	.199
160	.706	.59	11.22	Pitching .49 deg about $x_a/c = .404$	46.2	.298
161	.706	.59	11.22	Pitching 1.01 deg about $x_a/c = .398$	7.7	.050
162	.706	.59	11.22	Pitching 1.00 deg about $x_a/c = .398$	30.8	.199
163	.706	.59	11.22	Pitching 2.01 deg about $x_a/c = .401$	7.7	.050
164	.706	.59	11.22	Pitching 2.00 deg about $x_a/c = .402$	30.8	.199
165	.706	.59	11.22	Plunging 1.00 cm (0.393 in.)	7.7	.050
166	.706	.59	11.22	Plunging 1.00 cm (0.392 in.)	30.8	0.199
167	.505	.58	9.34	Pitching .53 deg about $x_a/c = .396$	2.8	.025
168	.505	.58	9.34	Pitching .51 deg about $x_a/c = .401$	5.5	.049
169	.505	.58	9.34	Pitching .50 deg about $x_a/c = .403$	11.0	.099
170	.505	.58	9.34	Pitching .50 deg about $x_a/c = .404$	22.0	.198
171	.505	.58	9.34	Pitching .40 deg about $x_a/c = .404$	33.0	.297
172	.505	.58	9.34	Pitching 1.02 deg about $x_a/c = .399$	5.5	.049
173	.505	.58	9.34	Pitching 1.01 deg about $x_a/c = .399$	22.0	.198
174	.505	.58	9.34	Pitching 1.04 deg about $x_a/c = .400$	5.5	.049
175	.505	.58	9.34	Pitching 2.01 deg about $x_a/c = .402$	22.0	.198
176	.505	.58	9.34	Plunging 1.01 cm (0.396 in.)	5.5	.049
177	.505	.58	9.34	Plunging .99 cm (0.396 in.)	22.0	.198
178	.712	.58	3.09	Pitching .50 deg about $x_a/c = .403$	7.4	.049
179	.712	.58	3.09	Pitching .49 deg about $x_a/c = .403$	29.7	.197
180	.712	.58	3.09	Pitching 2.02 deg about $x_a/c = .402$	7.4	.049
181	.712	.58	3.09	Pitching 2.00 deg about $x_a/c = .402$	29.7	.197
182	.712	.58	3.09	Plunging 1.00 cm (0.394 in.)	7.4	.049
183	.712	.58	3.09	Plunging .98 cm (0.398 in.)	29.7	.197
184	.508	.58	2.54	Pitching .50 deg about $x_a/c = .402$	5.4	.050
185	.508	.58	2.54	Pitching .50 deg about $x_a/c = .405$	21.4	.197
186	.508	.58	2.54	Pitching 2.03 deg about $x_a/c = .400$	5.4	.050
187	.508	.58	2.54	Pitching 2.00 deg about $x_a/c = .401$	21.4	.197
188	.508	.58	2.54	Plunging 1.01 cm (0.396 in.)	5.4	.050
189	.508	.58	2.54	Plunging .99 cm (0.398 in.)	21.4	.197
190	.752	.37	3.25	Pitching .50 deg about $x_a/c = .403$	7.8	.050
191	.752	.37	3.25	Pitching .50 deg about $x_a/c = .401$	31.4	.200

TABLE 5.1. CONCLUDED

DI	M	a_m , deg	$Re \times 10^{-6}$	Motion	f, Hz	k
192	0.752	0.37	3.25	Pitching 2.02 deg about $x_0/c = 0.401$	7.8	0.050
193	.752	.37	3.25	Pitching 2.00 deg about $x_0/c = .401$	31.4	.200
194	.752	.37	3.25	Plunging 1.00 cm (0.394 in.)	7.8	.050
195	.812	.35	3.29	Pitching .50 deg about $x_0/c = .403$	8.4	.050
196	.812	.35	3.29	Pitching .50 deg about $x_0/c = .404$	33.4	.198
197	.700	2.53	11.80	Pitching .49 deg about $x_0/c = .406$	7.5	.050
198	.700	2.53	11.80	Pitching .49 deg about $x_0/c = .405$	30.2	.201
199	.700	2.53	11.80	Pitching 1.01 deg about $x_0/c = 0.398$	7.5	0.050
200	.700	2.53	11.80	Pitching 1.00 deg about $x_0/c = .399$	30.2	.201
201	.700	2.53	11.80	Pitching 1.31 deg about $x_0/c = .403$	7.5	.050
202	.700	2.54	11.69	Plunging 1.00 cm (0.395 in.)	7.5	.050
203	.700	2.54	11.69	Plunging .86 cm (0.339 in.)	30.2	.201
204	.710	2.53	3.15	Pitching .50 deg about $x_0/c = .403$	7.4	.050
205	.710	2.53	3.15	Pitching .50 deg about $x_0/c = .403$	29.5	.199
206	.710	2.53	3.15	Pitching 1.01 deg about $x_0/c = .400$	7.4	.050
207	.710	2.53	3.15	Pitching 1.00 deg about $x_0/c = .399$	29.5	.199
208	.710	2.53	3.15	Plunging 1.01 cm (0.398 in.)	7.4	.050
209	.710	2.53	3.15	Plunging .87 cm (0.341 in.)	29.5	.199

TABLE 5.2. DATA BASE FOR NLR 7301 AIRFOIL, PITCHING OSCILLATION ABOUT 0.40c, ARRANGED IN FREQUENCY SWEEPS

M	a_m , deg	$Re \times 10^{-6}$	a_0 , deg	$k = 0.025$	$k = 0.05$	$k = 0.10$	$k = 0.15$	$k = 0.20$	$k = 0.25$	$k = 0.30$
.75	0.37	3.3	± 0.50		190			191		
.75	.37	6.2	± 0.50	131	132	133		134		135
.75	.37	11.5	± 0.50	145	144	146	147	148		149
.75	.37	6.2	± 1		136			137		
.75	.37	11.5	± 1		150			151		
.75	.37	3.3	± 2		192			193		
.75	.37	6.2	± 2		138			139		
.75	.37	11.5	± 2		152			153		
.80	.37	3.3	± 0.50		195			196		
.80	.37	6.3	± 0.50		140			141		
.80	.37	11.7	± 0.50		143			143		
.90	.57	2.8	± 0.50		184			185		
.45	.57	4.5	± 0.50	115	116	117		118		119
.50	.57	9.3	± 0.50	167	168	169		170		171
.45	.57	4.5	± 1		120			121		
.50	.57	9.5	± 1		172			173		
.50	.57	2.5	± 2		186			187		
.45	.57	4.5	± 2		172			123		
.50	.57	9.3	± 2		174			175		
.71	.57	3.1	± 0.50		178			179		
.70	.57	6.2	± 0.50	124	129			126		
.70	.57	11.2	± 0.50	156	157	158		159		160
.70	.57	6.2	± 1		127			128		
.70	.57	11.2	± 1		161			162		
.71	.57	3.1	± 2		180			181		
.70	.57	6.2	± 2		129			130		
.70	.57	11.2	± 2		163			164		
.70	2.5	3.2	± 0.5		204			205		
.70	2.5	11.8	± 0.5		197			198		
.70	2.5	3.2	± 1		206			207		
.70	3.5	11.8	± 1		199			200		

TABLE 5.3. NASA AMES TEST DATA ASSOCIATED WITH AGARD CT CASES

Flow	CT case						Data set 5						Data table no.
	No.	M	α_m	α_o	k	DI no.	M	α_m	α_o	k	$Rex \times 10^{-6}$		
Subsonic	1	0.500	0.40	0.5	0.098	184	0.508	0.58	0.50	0.050	2.53	5.4	
						168	0.505	0.58	0.51	0.049	9.33	5.5	
Transonic with shock	2	0.500	0.40	0.5	0.263	185	0.508	0.58	0.50	0.197	2.53	5.6	
						170	0.505	0.58	0.50	0.198	9.33	5.7	
Supercritical design	3	0.700	2.00	0.5	0.072	204	0.710	2.53	0.50	0.050	3.14	5.8	
						197	0.700	2.53	0.49	0.050	12.0	5.9	
Supercritical design	4	0.700	2.00	1.0	0.072	206	0.710	2.53	1.01	0.050	3.14	5.10	
						199	0.700	2.53	1.01	0.050	12.0	5.11	
Supercritical design	5	0.700	2.00	0.5	0.192	205	0.710	2.53	0.58	0.199	3.14	5.12	
						198	0.700	2.53	0.49	0.201	12.0	5.13	
Supercritical design	6	0.721	-0.19	0.5	0.068	190	0.752	0.37	0.50	0.050	3.30	5.14	
						132	0.752	0.37	0.50	0.050	6.20	5.15	
Supercritical design	7	0.721	-0.19	1.0	0.068	144	0.751	0.37	0.50	0.050	11.4	5.16 & 5.24	
						136	0.752	0.37	1.01	0.050	6.20	5.17	
Supercritical design	8*	0.721	-0.19	0.5	0.181	150	0.751	0.37	1.00	0.050	11.4	5.18	
						191	0.752	0.37	0.50	0.200	3.30	5.19	
Supercritical design	9	0.721	-0.19	0.5	0.453	134	0.752	0.37	0.49	0.290	6.20	5.20	
						148	0.751	0.37	0.50	0.201	11.4	5.21 & 5.25	
Supercritical design	10	0.721	-0.19	0.5	0.453	135	0.752	0.37	0.50	0.300	6.20	5.22	
						149	0.751	0.37	0.50	0.301	11.4	5.23	

* denotes priority case.

TABLE 5.4. MEA. AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 1: DYNAMIC INDEX 184

WING MODEL: MLR 7201 SUPERCRITICAL CHORD: 300 METERS

WING MOTION PITCHING: 10 DEG. ABOUT X/C: 0.62

DYNAMIC INDEX 184 STATIC INDEX 80

W	520	P _{TOT}	0.0004	E	0.00
ALPHA	50	Q _{INF}	0.00	PGO	0.0
RE	2.5E+03	P _{INF}	0.0000		

UPPER SURFACE				LOWER SURFACE				
STEADY DATA		UNSTEADY DATA		STEADY DATA		UNSTEADY DATA		
CPL								
E/C	CPL	E/C	REAL	W/E	PAG	W/E	PAG	
045	-0.100	048	-0.007	2.410	17.721	170.50	053	+ 310
070	-0.062	067	+0.000	2.400	17.500	170.67	166	+ 337
094	-0.038	092	+0.154	0.493	9.200	172.36	366	+ 337
122	-0.038	117	+0.260	1.269	9.200	171.68	359	+ 418
147	-0.035	142	+0.501	1.617	7.715	171.43	261	+ 270
166	-0.043	161	+0.637	2.025	9.211	172.11	460	+ 369
195	-0.012	200	+0.194	0.527	4.322	172.66	632	+ 310
224	-0.005	220	+0.257	0.76	4.293	173.64	616	+ 127
252	+0.010	249	+0.216	0.494	0.629	173.49	696	+ 644
281	+0.011	292	+0.644	0.112	3.609	172.62	719	+ 218
310	+0.004	300	+0.079	0.644	2.621	169.32	630	+ 234
339	+0.002	327	+0.153	0.984	2.059	167.00		
368	+0.020	429	+0.953	2.759	2.00	170.91		
396	+0.018	446	+2.304	2.27	2.227	171.93		
425	+0.000	470	+2.018	2.600	2.623	171.37		
453	+0.017	477	+2.226	2.64	2.234	173.20		
482	+0.012	497	+0.817	1.66	2.693	171.53		
510	+0.006	500	+1.000	0.69	1.701	170.24		
539	+0.003	555	+1.043	1.01	1.647	170.00		
568	+0.008	610	+1.272	0.63	1.273	177.39		
596	+0.019	647	+1.179	0.69	1.140	177.83		
625	+0.007	657	+1.000	0.14	2.00	170.98		
653	+0.006	700	+2.05	1.63	2.07	+173.83		
682	+0.003	700	+2.27	1.79	2.79	+161.83		
710	+0.000	641	+0.807	0.71	1.08	+120.82		
739	+0.013	646	+0.302	1.30	2.06	+120.20		
767	+0.001	644	+0.001					

TABLE 5.5. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 1; DYNAMIC INDEX 168

WING MODEL: NLR 7301 SUPERCRITICAL, CHORD= 500 METERS

WING MOTION: PITCHING .51 DEG ABOUT X/C= 401

DYNAMIC INDEX 168 STATIC INDEX 78

H	.505	PTOT	203067	K	049
ALPHA	.58	QINF	30419.	FREQ	5 5
RE	9.33E.06	PINF	170653.		

-----UPPER SURFACE-----

STEADY DATA

UNSTEADY DATA

----CPU----

X/C	CPU	X/C	REAL	IMAG	MAG	PHASE
.023	-1.201	.016	-18.059	3.167	18.335	170.07
.045	-1.176	.067	-16.240	2.509	16.442	171.02
.070	-0.953	.092	-8.348	1.623	8.505	169.01
.094	-0.669	.117	-2.658	.418	2.700	171.10
.122	-0.753	.142	-2.074	.347	2.103	170.50
.147	-0.715	.164	-2.154	.303	2.175	172.01
.168	-0.682	.191	-6.073	.849	6.132	172.06
.195	-0.645	.245	-4.041	.659	4.096	170.61
.249	-0.635	.294	-4.131	.518	4.163	172.87
.297	-0.619	.319	-3.786	.484	3.817	172.72
.321	-0.622	.343	-3.631	.460	3.660	172.79
.348	-0.616	.366	-2.569	.379	2.797	171.63
.369	-0.608	.393	-2.554	.434	2.590	170.36
.396	-0.550	.424	-3.012	.304	3.027	174.26
.420	-0.535	.448	-1.784	.249	1.802	172.06
.450	-0.584	.470	-2.436	.168	2.451	173.73
.473	-0.593	.497	-2.093	.163	2.109	172.78
.499	-0.597	.547	-2.075	.281	2.094	172.30
.524	-0.587	.569	-1.847	.207	1.850	173.63
.550	-0.598	.595	-1.511	.173	1.521	173.49
.578	-0.579	.618	-1.769	.154	1.776	175.04
.600	-0.545	.647	-1.196	.107	1.201	174.89
.624	-0.498	.697	-5.63	.057	.566	174.23
.652	-0.432	.746	-7.736	.037	.737	177.17
.700	-0.379	.796	-3.386	-.000	.386	-179.99
.749	-0.281	.841	-1.281	-.015	.281	-177.01
.797	-0.170	.916	1.483	-.081	1.485	-3.13
842	-0.065					
914	-0.078					

-----LOWER SURFACE-----

STEADY DATA

UNSTEADY DATA

----CPL----

X/C	CPL	X/C	REAL	IMAG	MAG	PHASE
.053	-284	.106	-3.313			
.106	-3.317	.309	-3.399			
.381	-3.370	.460	-3.390			
.532	-3.315	.614	-3.117			
.684	-0.059	.779	-0.230			
.874	3.339					

TABLE 5.6. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 2; DYNAMIC INDEX 185

WING MODEL: NLR 7301 SUPERCRITICAL, CHORD= 500 METERS

WING MOTION: PITCHING .50 DEG ABOUT X/C= 405

DYNAMIC INDEX 185 STATIC INDEX 80

H	.508	PTOT	50864	K	197
ALPHA	.58	QINF	7692	FREQ	21.4
RE	2.53E.06	PINF	42556		

-----UPPER SURFACE-----

STEADY DATA

UNSTEADY DATA

----CPU----

X/C	CPU	X/C	REAL	IMAG	MAG	PHASE
.046	-1.146	.016	-13.312	5.910	14.595	168.07
.070	-0.865	.067	-13.205	5.623	14.353	158.95
.094	-0.826	.092	-4.410	1.341	4.609	163.09
.122	-0.704	.117	-5.369	2.261	5.759	160.47
.147	-0.676	.142	-5.276	1.797	5.573	161.21
.168	-0.663	.191	-4.270	1.253	4.450	163.68
.195	-0.612	.245	-3.396	.713	3.470	168.16
.249	-0.565	.294	-3.054	.676	3.126	167.64
.297	-0.590	.319	-3.056	.526	3.101	170.29
.321	-0.601	.343	-2.567	.618	2.634	162.34
.348	-0.594	.366	-1.878	.792	2.039	167.14
369	.580	.393	-3.019	.877	2.201	156.55
396	.524	.424	-2.177	.095	2.179	177.51
420	.515	.448	-1.319	.397	1.687	166.26
460	.560	.470	-1.785	.044	1.786	178.62
.473	.579	.497	-1.638	.004	1.636	179.88
.499	.572	.647	-1.423	-.072	1.425	-177.13
.524	.559	.569	-1.126	.160	1.140	-170.94
.550	.660	.505	-0.907	.037	.908	177.58
.578	.648	.618	-0.910	.220	.937	-168.43
.600	.519	.647	-0.780	.246	.818	-162.49
.624	.467	.697	-0.493	.347	.579	-143.21
.652	.403	.746	-0.212	.364	.422	-120.26
.700	.353	.796	-0.147	.399	.425	-110.28
.749	.260	.841	-0.266	.831	.874	-107.90
.797	.105	.916	-0.274	.238	.363	-139.00
842	.061					
914	.081					

-----LOWER SURFACE-----

STEADY DATA

UNSTEADY DATA

----CPL----

X/C	CPL	X/C	REAL	IMAG	MAG	PHASE
.053	-316	.106	-3.337			
.209	-3.337	.309	-4.416			
.381	-4.374	.460	-3.398			
.532	-3.318	.614	-3.122			
.684	0.044	.779	2.116			
.874	-0.334					

TABLE 5.7. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 2; DYNAMIC INDEX 170
WING MODEL: M.B. 7301 SUPERCRITICAL CHORD: 500 METERS

WING MOTION: PITCHING 50 DEG ABOUT X/C: 48A

DYNAMIC INDEX 170 STATIC INDEX 78

406 0101 2023-53

ALPHA 5S QINF 30419 FREQ 22
RE 9 33E 06 PINF 170663

.....UPPER SURFACE

---LOWER SURFACE

TABLE 5.8. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 3; DYNAMIC INDEX 204
WING MODEL, NLR 7301 SUPERCRITICAL, CHORD 500 METERS

WING MOTION: PITCHING 30 DEG ABOUT X/C 400

DYNAMIC INDEX 204 STATIC INDEX 89

M 710 PTOT 50968 X 0

...UPPER SURFACE

... LOWER SURFACE

TABLE 5.9. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 3; DYNAMIC INDEX 197
 WING MODEL: NLR 7301 SUPERCRITICAL, CHORD= 500 METERS

WING MOTION. PITCHING 49 DEG ABOUT X/C= 406

DYNAMIC INDEX 197 STATIC INDEX 83

H	.700	PTOT	203135.	K	050
ALPHA	2 53	QINF	50262	FREQ	7.5
RE	1 20E 07	PINF	146405.		

TABLE 5.10. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 4; DYNAMIC INDEX 206
WING MODEL: MLR 7301 SUPERCRITICAL, CHM0 = 500 METERS

WING MOTION: PITCHING 1.01 DEG ABOUT X/C. 400

DYNAMIC INDEX 208 STATIC INDEX 97

M	710	PTOT	50068	K	000
ALPHA	2.53	QINF	12840	FREQ	74
RE	3.14E-06	PINF	38427		

TABLE 5.11. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 5; DYNAMIC INDEX 1999

VING MODEL: NLB 7301 SUPERCRITICAL CHARGE: 500 METERS

WING MOTION PITCHING 1.01 DEG ABOUT X/C 398

DYNAMIC INDEX 199 STATIC INDEX 83

M	700	PTOT	203135.	K	05
ALPHA	2.53	QINF	50262	FREQ	7
RE	1.20E-07	PINF	145405		

-----UPPER SURFA

.....LOWER SURFACE

TABLE 5.12. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 5; DYNAMIC INDEX 205

WING MODEL: NLR 7301 SUPERCRITICAL, CHORD: 500 METERS

WING MOTION: PITCHING 50 DEG ABOUT X/C: 40

DYNAMIC INDEX 203 STATIC INDEX 87

M	710	PTOT	50965	K	194
ALPHA	2.53	QINF	12840	FREQ	29.1
RE	3.14E-06	PINF	36427		

.....UPPER SURF

.....LOWER SURFACE

TABLE 5.13. MEAN AND FLUCTUATIONAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 5; DYNAMIC INDEX 198

WING MODEL: NLR 7301 SUPERCRITICAL, CHORD= 500 METERS

WING MOTION: PITCHING - 9 DEG ABOUT X/C: - 405

DYNAMIC INDEX 198 STATIC INDEX 83

M	700	PTJT	203135	K	201
ALPHA	2 53	QINF	50262.	FREQ	30 2
RE	1.20E 07	PINF	146405		

.....UPPER SURFACE

.....-LOWER SURFACE-.....

TABLE 5.14. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 6; DYNAMIC INDEX 190
WING MODEL: NLR 7.01 SUPERCRITICAL, CHORD: 600 METERS

WIND MOTION PITCHING 50 DEG ABOUT X.G. 403

DYNAMIC INDEX 190 STATIC INDEX 8

H 752 PTOT 50968

RE 330E 08 PINE 35026

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TABLE 5.15. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 6; DYNAMIC INDEX 132

WING MODEL: N.B. 7301 SUPERCRITICAL CHORD: 500 METERS

WING MOTION: PITCHING 5G DEG ABOUT X/C: 481

DYNAMIC INDEX 132 STATIC INDEX 73

M	752	PTOT	101661	K	050
ALPHA	37	QINF	27671	FREQ	8 0
RE	6.20E-06	PINF	69950		

-----UPPER SURFACE

-----LOWER SURFACE-----

STEADY DATA

UNSTEADY DATA

STEADY DATA

UNSTEADY DATA

X/C	CPU	X/C	REAL	IMAG	HAG	PHASR
023	- .564	.016	-5 217	1 972	5 577	159 30
045	-1 095	-067	-8 618	3 247	9 229	159 37
070	-1 064	092	-6 838	2 756	7 373	158 40
094	-1 136	117	-7 952	3 046	8 516	159 04
122	-1 105	142	-8 721	3 526	9 407	158 00
147	-1 062	164	-8 699	3 487	9 372	158 11
168	-1 065	191	-8 007	3 337	8 674	157 30
195	-1 028	245	-8 859	4 008	9 723	155 61
249	- .970	294	-9 900	4 553	10 597	155 31
297	-1 004	.319	-9 363	4 405	10 348	154 82
321	-1 007	343	-9 807	4 984	11 001	153 07
348	-1 015	393	-11 767	9 664	15 227	140 61
369	-1 052	424	-15 856	9 453	18 420	149 21
396	-1 044	470	-14 543	8 621	16 906	149 31
420	- .991	497	-14 666	9 139	17 298	148 12
450	- .990	547	-17 600	12 269	21 454	145 11
473	-1 015	595	5 924	-10 658	12 220	-61 C
499	-1 016	.618	5 193	-9 932	11 208	-62 40
524	-1 045	.647	-3 277	-540	3 321	-173 65
550	-1 085	.697	-1 904	.099	1 908	177 02
578	-1 003	.748	- .921	.011	.921	-179 31
600	- .808	.796	-1 033	.205	1 054	168 81
624	- .639	.841	- .416	.057	.420	172 27
652	- .492	.916	- .592	- .555	.811	-49 14
700	- .365					
749	- .243					
787	- .126					
802	- .023					
944	- .109					

X/C	CPL	X/C	REAL	IMAG	MAG	PHAS
C33	258					
C53	- 592					
106	- 512					
209	- 416					
309	- 721					
381	- 667					
460	- 602					
532	- 430					
614	- 128					
684	068					
779	245					
874	352					

TABLE 5.16. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 6; DYNAMIC INDEX 144
 WING MODEL: NLR 7301 SUPERCRITICAL, CHORD: 500 METERS

10. The following table summarizes the results of the study.

ONE HUNDRED FIFTY-FIVE SEVEN HUNDRED

H	751	PTOT	203236	K	050
ALPHA	37	QINF	65173	FREQ	0 2
PC	1 145.07	PINF	138844		

.....-UPPER SURFACE

.....LOWER SURFACE -

STEADY DATA

UNSTEADY DATA

STEADY STATE

UNSTEADY DATA

CPU-A				CPU-B			
X/C	CPU	X/C	REAL	X/HG	HAC	X/HG	PHASE
.023	- .962	.016	- .922	1 .979	0 .971	158 .971	
.045	- .946	.067	- .950	3 .109	0 .130	159 .950	
.070	- .936	.082	- .948	2 .963	7 .997	158 .210	
.084	- .931	.117	- .958	3 .015	0 .810	159 .240	
.127	- .987	.162	- .940	3 .793	10 .145	158 .145	
.147	- .943	.164	- .922	3 .540	9 .606	158 .240	
.168	- .959	.191	- .910	3 .400	8 .753	157 .250	
.195	- .921	.245	- .967	4 .973	11 .797	157 .797	
.249	- .956	.294	- .912	7 .932	15 .924	160 .110	
.297	- .991	.319	- .949	8 .466	16 .437	169 .010	
.321	- .900	.343	- .917	9 .824	18 .320	149 .100	
.348	- .932	.293	- .917	10 .291	18 .559	145 .940	
.369	- .952	.424	- .917	9 .465	19 .959	151 .700	
.396	- .952	.470	- .918	8 .911	20 .049	157 .640	
.420	- .973	.497	- .958	8 .644	19 .645	154 .160	
.450	- .920	.547	- .916	7 .972	18 .196	154 .010	
.473	- .964	.595	- .924	-10 .372	20 .597	143 .830	
.499	- .905	.618	- .926	-16 .417	23 .273	-30 .260	
.524	- .949	.647	- .923	-2 .967	8 .824	-30 .510	
.550	- .999	.667	- .726	-6 .687	1 .658	-31 .710	
.578	- .764	.746	- .910	-2 .298	7 .062	-18 .050	
.630	- .633	.798	- .393	-3 .393	450	-34 .740	
.624	- .625	.841	- .216	-2 .220	366	-55 .900	
.652	- .440	.916	- .966	-5 .510	1 .121	-27 .060	
.700	- .353						
.749	- .234						
.797	- .110						
.842	- .008						
.914	- .122						

TABLE 5.17. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 7; DYNAMIC INDEX 136

WING MODEL: NLR 7301 SUPERCRITICAL, CHORD= 500 METERS

WING MOTION PITCHING 1.01 DEG ABOUT X/C* 338

DYNAMIC INDEX 136 STATIC INDEX 73

H	752	PTOT	101661	K	050
ALPHA	37	QINF	27671	FREQ	8 C
RF	6 20E 06	PINF	69850		

TABLE 5.18. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 7; DYNAMIC INDEX 150

WING MODEL: M.B. 7301 SUPERCRITICAL. CHORD: 500 METERS

WING MOTION: PITCHING 1.00 DEG ABOUT X/C. 300

DYNAMIC INDEX 150 STATIC INDEX 76

H 751 **PTOT** 203236

PC 146 07 PINE 120846

STEADY DATA	UNSTEADY DATA	STEADY DATA	UNSTEADY DATA
CPU	CPU,A	CPU	CPU,A
1/E	E/C	1/E	1/E
025	- 362	016	- 6 240
045	- 1 048	067	- 9 033
070	- 1 026	082	- 8 040
084	- 1 131	117	- 8 847
122	- 1 087	142	- 10 254
147	- 1 043	164	- 10 801
168	- 1 059	181	- 13 624
195	- 1 031	245	- 12 661
249	- 358	264	- 11 470
297	- 991	319	- 10 264
321	- 1 000	347	- 10 195
348	- 1 009	393	- 9 545
369	- 1 052	424	- 9 876
395	- 1 052	470	- 10 645
420	- 973	497	- 10 522
450	- 920	647	- 9 487
473	- 964	539	- 9 459
479	- 805	618	- 9 397
524	- 949	647	- 9 358
560	- 999	697	- 776
578	- 764	746	- 673
600	- 837	798	- 175
624	- 825	841	- 662
632	- 440	916	- 322
700	- 363		
749	- 234		
797	- 110		
842	- 006		
814	- 122		

TABLE 5.19. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 8; DYNAMIC INDEX 1911

WING MODEL: NLR 7301 SUPERCRITICAL, CHORD: 500 METERS

WING MOTION PITCHING 50 DEG ABOUT X/C= 401

DYNAMIC INDEX 191 STATIC INDEX 81

M	.752	PTOT	60966.	K	200
ALPHA	37	QINF	13866.	FREQ	31 4
RE	3 30E 06	PINF	35026		

TABLE 5.20. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 8; DYNAMIC INDEX 134

WING MODEL: NLR 7001 SUPERCRITICAL, CHORD: 500 METERS

WING MOTION PITCHING 49 DEG ABOUT

DYNAMIC INDEX 134 STATIC INDEX 73

TABLE 5.21. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 8; DYNAMIC INDEX 148

WING MODEL: MLR 7301 SUPERCRITICAL, CHORD= 500 METERS

WING MOTION. PITCHING 50 DEG ABOUT X/C. 403

DYNAMIC INDEX 148 STATIC INDEX 76

M	751	PTOT	203236.	K	201
ALPHA	37	QINF	55173	FREQ	33 0
RE	1.14E 07	PINF	139846.		

TABLE 5.22. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 9; DYNAMIC INDEX 135
 VING MODEL: M.R. 730; SUPERCRITICAL; CHORD: 500 METRES

...the first time I ever saw a real live dragon.

WING POSITION. PITCHING. 50 DEC ABSUT

GRADE TABLE FOR STATIC INDEX 75

TABLE 5.23. MEAN AND FUNDAMENTAL FREQUENCY PRESSURE FOR AGARD CT CASE NO. 9; DYNAMIC INDEX 149

WING MODEL, NLR 7301 SUPERCRITICAL, CHORD= 500 METERS

WING MOTION PITCHING 50 DEG ABOUT X/C. 400

DYNAMIC INDEX 149 STATIC INDEX 76

M	751	PTOT	203236	K	301
ALPHA	37	QINF	55173	FREQ	49.5
RE	1.14E 07	PINF	139846		

TABLE 5.24. INSTANTANEOUS PRESSURES AT THE UPPER SURFACE, HIGH REYNOLDS NUMBER
 DATA: CT CASE 6; DYNAMIC INDEX 144

	1	2	3	4	5	6	7	8	9	10	11	12
PHASE	0.000	30.7	61.7	90.7	90.7	61.7	30.7	0.000	61.7	90.7	90.7	100.7
ALPHA	0.000	0.300	0.500	0.500	0.200	0.200	0.100	0.100	0.070	0.020	0.020	0.000
B/C	*	*	*	*	*	*	*	*	C/P	*	*	*
1	-0.016	-0.207	-0.266	-0.263	-0.000	-0.257	-0.150	-0.249	-0.000	-0.248	-0.237	-0.220
2	-0.007	-0.199	-0.192	-0.090	-0.199	-0.189	-0.095	-0.179	-0.073	-0.099	-0.099	-0.001
3	-0.092	-0.190	-0.160	-0.160	-0.183	-0.170	-0.175	-0.170	-0.165	-0.159	-0.131	-0.130
4	-0.117	-0.172	-0.170	-0.167	-0.163	-0.150	-0.150	-0.148	-0.142	-0.126	-0.121	-0.113
5	-0.142	-0.160	-0.125	-0.122	-0.110	-0.113	-0.107	-0.100	-0.095	-0.086	-0.077	-0.069
6	-0.160	-0.137	-0.124	-0.131	-0.147	-0.162	-0.162	-0.160	-0.163	-0.169	-0.170	-0.161
7	-0.161	-0.102	-0.090	-0.090	-0.092	-0.087	-0.081	-0.076	-0.060	-0.062	-0.056	-0.049
8	-0.249	-0.097	-0.095	-0.093	-0.090	-0.080	-0.070	-0.061	-0.059	-0.057	-0.050	-0.042
9	-0.265	-0.101	-0.090	-0.095	-0.091	-0.086	-0.080	-0.073	-0.065	-0.056	-0.047	-0.037
10	-0.219	-0.111	-0.100	-0.100	-0.101	-0.098	-0.091	-0.085	-0.077	-0.070	-0.063	-0.051
11	-0.203	-0.121	-0.120	-0.120	-0.121	-0.118	-0.111	-0.105	-0.098	-0.092	-0.084	-0.071
12	-0.203	-0.121	-0.107	-0.104	-0.102	-0.108	-0.104	-0.100	-0.103	-0.107	-0.102	-0.092
13	-0.203	-0.121	-0.107	-0.104	-0.102	-0.108	-0.104	-0.100	-0.103	-0.107	-0.102	-0.092
14	-0.226	-0.113	-0.111	-0.100	-0.105	-0.100	-0.095	-0.087	-0.080	-0.073	-0.068	-0.059
15	-0.270	-0.093	-0.091	-0.093	-0.092	-0.086	-0.089	-0.082	-0.072	-0.061	-0.052	-0.045
16	-0.297	-0.073	-0.070	-0.067	-0.062	-0.059	-0.059	-0.061	-0.050	-0.049	-0.041	-0.037
17	-0.305	-0.107	-0.102	-0.100	-0.107	-0.100	-0.102	-0.102	-0.090	-0.088	-0.082	-0.076
18	-0.305	-0.101	-0.102	-0.100	-0.107	-0.100	-0.102	-0.102	-0.090	-0.088	-0.082	-0.076
19	-0.305	-0.101	-0.102	-0.100	-0.107	-0.100	-0.102	-0.102	-0.090	-0.088	-0.082	-0.076
20	-0.307	-0.020	-0.017	-0.015	-0.013	-0.012	-0.010	-0.008	-0.005	-0.003	-0.001	-0.001
21	-0.307	-0.020	-0.017	-0.015	-0.013	-0.012	-0.010	-0.008	-0.005	-0.003	-0.001	-0.001
22	-0.305	-0.020	-0.017	-0.015	-0.013	-0.012	-0.010	-0.008	-0.005	-0.003	-0.001	-0.001
23	-0.305	-0.020	-0.017	-0.015	-0.013	-0.012	-0.010	-0.008	-0.005	-0.003	-0.001	-0.001
24	-0.305	-0.020	-0.017	-0.015	-0.013	-0.012	-0.010	-0.008	-0.005	-0.003	-0.001	-0.001

TABLE 5.24. CONTINUED.

	Jx	14	15	16	17	18	19	20	21	22	23	24	25	26
PHASE,DEGR	116.7	122.7	128.7	134.7	140.7	146.7	152.7	158.7	164.7	170.7	176.7	182.7	188.7	
ALPHA,DEGR	-0.232	-0.276	-0.315	-0.349	-0.382	-0.413	-0.439	-0.460	-0.474	-0.475	-0.487	-0.487	-0.483	
1	X/C	*	*	*	*	*	*	*	*	*	*	*	*	*
2	.016	-0.217	-0.213	-0.208	-0.204	-0.199	-0.194	-0.190	-0.187	-0.184	-0.181	-0.178	-0.176	-0.175
3	.067	-1.023	-1.015	-1.008	-1.001	-0.995	-0.988	-0.982	-0.976	-0.971	-0.964	-0.959	-0.957	-0.954
4	.092	-1.123	-1.117	-1.111	-1.105	-1.099	-1.091	-1.084	-1.078	-1.073	-1.067	-1.064	-1.061	-1.059
5	.142	-1.045	-1.037	-1.028	-1.018	-1.010	-1.001	-0.993	-0.982	-0.973	-0.966	-0.960	-0.957	-0.951
6	.164	-1.052	-1.044	-1.035	-1.028	-1.021	-1.014	-1.007	-1.001	-0.996	-0.990	-0.986	-0.983	-0.979
7	.191	-1.027	-1.020	-1.013	-1.007	-1.001	-0.993	-0.987	-0.980	-0.975	-0.968	-0.963	-0.959	-0.955
8	.245	-0.981	-0.950	-0.930	-0.929	-0.919	-0.908	-0.899	-0.891	-0.884	-0.876	-0.869	-0.864	-0.858
9	.294	-1.011	-1.002	-0.992	-0.983	-0.976	-0.965	-0.953	-0.944	-0.934	-0.922	-0.914	-0.901	-0.886
10	.319	-1.030	-1.022	-1.013	-1.004	-0.997	-0.986	-0.976	-0.968	-0.958	-0.937	-0.922	-0.902	-0.887
11	.343	-1.053	-1.044	-1.033	-1.021	-1.011	-0.997	-0.980	-0.962	-0.944	-0.907	-0.852	-0.871	-0.766
12	.393	-1.114	-1.101	-1.087	-1.069	-1.050	-1.024	-0.972	-0.926	-0.906	-0.900	-0.891	-0.887	-0.892
13	.424	-1.006	-0.984	-0.955	-0.939	-0.906	-0.886	-0.830	-0.849	-0.846	-0.833	-0.815	-0.790	-0.750
14	.470	-0.854	-0.804	-0.787	-0.766	-0.792	-0.787	-0.779	-0.752	-0.710	-0.682	-0.659	-0.630	-0.646
15	.497	-0.857	-0.860	-0.859	-0.855	-0.856	-0.858	-0.853	-0.815	-0.739	-0.686	-0.663	-0.671	-0.687
16	.547	-1.005	-0.997	-0.986	-0.948	-0.858	-0.797	-0.795	-0.801	-0.819	-0.841	-0.860	-0.883	-0.909
17	.595	-0.845	-0.849	-0.813	-0.552	-0.608	-0.602	-0.752	-0.794	-0.835	-0.857	-0.887	-0.892	-0.899
18	.618	-0.814	-0.812	-0.441	-0.459	-0.479	-0.527	-0.585	-0.680	-0.758	-0.793	-0.808	-0.784	-0.700
19	.647	-0.425	-0.436	-0.481	-0.450	-0.460	-0.461	-0.470	-0.481	-0.496	-0.511	-0.531	-0.525	-0.531
20	.697	-0.364	-0.371	-0.374	-0.376	-0.381	-0.381	-0.378	-0.380	-0.376	-0.374	-0.372	-0.370	-0.372
21	.746	-0.266	-0.249	-0.251	-0.251	-0.252	-0.253	-0.254	-0.254	-0.251	-0.248	-0.247	-0.247	-0.247
22	.796	-0.112	-0.113	-0.113	-0.113	-0.113	-0.115	-0.114	-0.115	-0.115	-0.115	-0.116	-0.115	-0.116
23	.841	-0.006	-0.006	-0.007	-0.006	-0.006	-0.006	-0.007	-0.007	-0.008	-0.010	-0.010	-0.011	-0.012
24	.916	-0.129	-0.108	-0.131	-0.119	-0.120	-0.139	-0.089	-0.106	-0.110	-0.113	-0.124	-0.095	-0.101

	Jx	27	28	29	30	31	32	33	34	35	36	37	38	39
PHASE,DEGR	194.7	200.7	206.7	212.7	218.7	224.7	230.7	236.7	242.7	248.7	254.7	260.7	266.7	
ALPHA,DEGR	-0.475	-0.464	-0.460	-0.426	-0.397	-0.362	-0.321	-0.270	-0.220	-0.183	-0.134	-0.084	-0.031	
1	X/C	*	*	*	*	*	*	*	*	*	*	*	*	*
2	.016	-0.173	-0.173	-0.174	-0.173	-0.174	-0.176	-0.176	-0.182	-0.186	-0.189	-0.194	-0.190	-0.203
3	.067	-0.931	-0.930	-0.930	-0.932	-0.935	-0.939	-0.945	-0.972	-0.979	-0.986	-0.983	-0.981	-0.980
4	.092	-1.036	-1.056	-1.055	-1.055	-1.056	-1.056	-1.056	-1.062	-1.066	-1.071	-1.078	-1.083	-1.081
5	.117	-1.020	-1.028	-1.027	-1.027	-1.029	-1.032	-1.032	-1.041	-1.046	-1.056	-1.062	-1.071	-1.079
6	.142	-0.957	-0.956	-0.955	-0.955	-0.956	-0.956	-0.956	-0.965	-0.970	-0.977	-0.984	-0.993	-1.003
7	.164	-0.977	-0.976	-0.975	-0.975	-0.976	-0.976	-0.979	-0.982	-0.987	-0.993	-1.000	-1.007	-1.015
8	.191	-0.932	-0.930	-0.929	-0.929	-0.929	-0.929	-0.929	-0.936	-0.942	-0.948	-0.954	-0.962	-1.001
9	.245	-0.853	-0.848	-0.840	-0.841	-0.840	-0.843	-0.850	-0.860	-0.870	-0.888	-0.900	-0.911	-0.911
10	.294	-0.867	-0.860	-0.866	-0.866	-0.866	-0.866	-0.866	-0.874	-0.875	-0.881	-0.887	-0.893	-0.893
11	.319	-0.826	-0.798	-0.781	-0.776	-0.776	-0.776	-0.776	-0.782	-0.781	-0.786	-0.792	-0.797	-0.797
12	.343	-0.777	-0.769	-0.772	-0.788	-0.792	-0.792	-0.792	-0.799	-0.799	-0.805	-0.810	-0.817	-0.819
13	.384	-0.685	-0.683	-0.681	-0.681	-0.682	-0.684	-0.684	-0.694	-0.694	-0.697	-0.703	-0.708	-0.711
14	.424	-0.646	-0.650	-0.663	-0.671	-0.672	-0.672	-0.673	-0.681	-0.681	-0.687	-0.692	-0.697	-0.707
15	.470	-0.713	-0.723	-0.731	-0.726	-0.745	-0.735	-0.735	-0.742	-0.742	-0.748	-0.754	-0.761	-0.766
16	.507	-0.713	-0.714	-0.705	-0.699	-0.691	-0.692	-0.692	-0.692	-0.692	-0.696	-0.696	-0.696	-0.695
17	.535	-0.698	-0.696	-0.692	-0.681	-0.681	-0.679	-0.678	-0.675	-0.676	-0.676	-0.681	-0.682	-0.686
18	.563	-0.703	-0.699	-0.692	-0.682	-0.679	-0.679	-0.679	-0.682	-0.682	-0.685	-0.685	-0.685	-0.685
19	.607	-0.620	-0.620	-0.619	-0.619	-0.619	-0.619	-0.619	-0.620	-0.620	-0.620	-0.620	-0.620	-0.620
20	.637	-0.370	-0.372	-0.369	-0.366	-0.366	-0.367	-0.366	-0.366	-0.366	-0.366	-0.365	-0.366	-0.366
21	.676	-0.247	-0.246	-0.245	-0.245	-0.244	-0.244	-0.243	-0.244	-0.244	-0.245	-0.245	-0.244	-0.245
22	.716	-0.112	-0.117	-0.117	-0.116	-0.116	-0.116	-0.116	-0.115	-0.115	-0.115	-0.117	-0.116	-0.116
23	.751	-0.013	-0.013	-0.014	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015
24	.791	-0.104	-0.115	-0.120	-0.120	-0.120	-0.120	-0.120	-0.120	-0.120	-0.120	-0.120	-0.120	-0.120

	Jx	40	41	42	43	44	45	46	47	48	49	50	51	52
PHASE,DEGR	272.7	278.7	284.7	290.7	296.7	302.7	308.7	314.7	320.7	326.7	332.7	338.7	344.7	
ALPHA,DEGR	-0.469	-0.470	-0.471	-0.471	-0.472	-0.473	-0.473	-0.473	-0.474	-0.474	-0.475	-0.475	-0.475	-0.475
1	X/C	*	*	*	*	*	*	*	*	*	*	*	*	*
2	.016	-0.973	-0.973	-0.973	-0.972	-0.972	-0.972	-0.972	-0.971	-0.971	-0.970	-0.969	-0.968	-0.967
3	.067	-1.000	-1.015	-1.008	-1.001	-0.995	-0.988	-0.982	-0.976	-0.971	-0.964	-0.959	-0.957	-0.954
4	.092	-1.123	-1.117	-1.111	-1.105	-1.099	-1.091	-1.084	-1.078	-1.073	-1.067	-1.064	-1.061	-1.059
5	.117	-1.096	-1.091	-1.085	-1.079	-1.074	-1.066	-1.059	-1.052	-1.047	-1.041	-1.037	-1.034	-1.031
6	.142	-1.045	-1.037	-1.028	-1.018	-1.010	-1.001	-0.993	-0.986	-0.980	-0.973	-0.966	-0.960	-0.959
7	.164	-1.052	-1.044	-										

TABLE 5.24. CONCLUDED

	J=	53	54	55	56	57	58	59	60	61	62	63	64	65
PHASE,UEG=	350.7	356.7	362.7	368.7	374.7	380.7	386.7	392.7	398.7	404.7	410.7	416.7	422.7	
ALPHA,UEG=	.482	.486	.487	.483	.476	.465	.448	.427	.403	.372	.335	.291	.262	
I	x/C	*	*	*	*	*	*	*	*	*	*	*	*	*
1	.016	-.264	-.266	-.267	-.266	-.269	-.270	-.268	-.267	-.265	-.264	-.262	-.258	
2	.067	-.109	-.110	-.110	-.110	-.110	-.110	-.110	-.110	-.110	-.110	-.109	-.109	
3	.092	-.118	-.118	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.118	-.118	
4	.117	-.116	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.116	-.116	
5	.142	-.112	-.112	-.112	-.112	-.112	-.112	-.112	-.112	-.112	-.112	-.112	-.112	
6	.164	-.113	-.113	-.113	-.113	-.113	-.113	-.113	-.113	-.113	-.113	-.113	-.113	
7	.191	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105	
8	.205	-.109	-.104	-.104	-.104	-.104	-.104	-.104	-.104	-.104	-.104	-.104	-.104	
9	.294	-.104	-.106	-.109	-.101	-.102	-.103	-.104	-.102	-.100	-.098	-.095	-.098	
10	.319	-.110	-.105	-.108	-.110	-.110	-.112	-.113	-.113	-.112	-.110	-.106	-.101	
11	.343	-.112	-.112	-.112	-.110	-.112	-.113	-.113	-.113	-.112	-.110	-.112	-.117	
12	.393	-.117	-.117	-.117	-.118	-.118	-.118	-.118	-.118	-.118	-.118	-.117	-.117	
13	.424	-.110	-.110	-.110	-.113	-.114	-.114	-.114	-.116	-.115	-.113	-.112	-.101	
14	.470	-.101	-.021	-.026	-.029	-.031	-.031	-.032	-.032	-.030	-.028	-.025	-.021	
15	.497	-.053	-.061	-.066	-.070	-.073	-.074	-.075	-.075	-.074	-.071	-.068	-.063	
16	.547	-.147	-.165	-.174	-.180	-.184	-.186	-.189	-.187	-.188	-.180	-.174	-.165	
17	.595	-.531	-.524	-.532	-.530	-.529	-.529	-.528	-.522	-.523	-.519	-.514	-.508	
18	.616	-.422	-.424	-.428	-.434	-.430	-.429	-.429	-.428	-.425	-.424	-.415	-.408	
19	.647	-.417	-.421	-.423	-.426	-.425	-.425	-.425	-.424	-.420	-.417	-.412	-.410	
20	.697	-.344	-.343	-.344	-.347	-.345	-.344	-.343	-.345	-.342	-.343	-.340	-.340	
21	.746	-.232	-.230	-.232	-.233	-.231	-.232	-.232	-.232	-.231	-.230	-.228	-.229	
22	.796	-.109	-.102	-.109	-.110	-.110	-.109	-.108	-.108	-.107	-.106	-.107	-.106	
23	.861	-.006	-.007	-.004	-.006	-.006	-.007	-.007	-.007	-.007	-.006	-.006	-.005	
24	.916	.124	.138	.124	.117	.114	.117	.116	.115	.114	.113	.113	.110	

TABLE 5.25. INSTANTANEOUS PRESSURES AT THE UPPER SURFACE, HIGH REYNOLDS NUMBER DATA; CT CASE 8; DYNAMIC INDEX 148

	J=	1	2	3	4	5	6	7	8	9	10	11	12	13
PHASE,UEG=	1.5	7.5	13.5	19.5	25.5	31.5	37.5	43.5	49.5	55.5	61.5	67.5	73.5	
ALPHA,UEG=	.490	.485	.471	.456	.437	.414	.388	.356	.323	.295	.264	.230	.199	.151
I	x/C	*	*	*	*	*	*	*	*	*	*	*	*	*
1	.016	-.206	-.207	-.208	-.209	-.209	-.209	-.209	-.209	-.209	-.209	-.209	-.209	-.209
2	.067	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107
3	.092	-.101	-.103	-.105	-.105	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107	-.107
4	.117	-.100	-.104	-.108	-.108	-.108	-.108	-.108	-.108	-.108	-.108	-.108	-.108	-.108
5	.142	-.097	-.100	-.102	-.104	-.104	-.104	-.104	-.104	-.104	-.104	-.104	-.104	-.104
6	.164	-.104	-.104	-.104	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105	-.105
7	.191	-.101	-.098	-.095	-.093	-.092	-.091	-.090	-.089	-.088	-.087	-.086	-.085	-.084
8	.205	-.095	-.094	-.093	-.092	-.091	-.090	-.089	-.088	-.087	-.086	-.085	-.084	-.083
9	.240	-.081	-.083	-.084	-.084	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083
10	.319	-.087	-.088	-.088	-.088	-.087	-.087	-.087	-.087	-.087	-.087	-.087	-.087	-.087
11	.343	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083	-.083
12	.393	-.079	-.079	-.079	-.079	-.079	-.079	-.079	-.079	-.079	-.079	-.079	-.079	-.079
13	.424	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074
14	.470	-.065	-.065	-.065	-.065	-.065	-.065	-.065	-.065	-.065	-.065	-.065	-.065	-.065
15	.497	-.062	-.062	-.062	-.062	-.062	-.062	-.062	-.062	-.062	-.062	-.062	-.062	-.062
16	.547	-.053	-.053	-.053	-.053	-.053	-.053	-.053	-.053	-.053	-.053	-.053	-.053	-.053
17	.595	-.049	-.049	-.049	-.049	-.049	-.049	-.049	-.049	-.049	-.049	-.049	-.049	-.049
18	.616	-.045	-.045	-.045	-.045	-.045	-.045	-.045	-.045	-.045	-.045	-.045	-.045	-.045
19	.647	-.041	-.041	-.041	-.041	-.041	-.041	-.041	-.041	-.041	-.041	-.041	-.041	-.041
20	.697	-.037	-.037	-.037	-.037	-.037	-.037	-.037	-.037	-.037	-.037	-.037	-.037	-.037
21	.746	-.033	-.033	-.033	-.033	-.033	-.033	-.033	-.033	-.033	-.033	-.033	-.033	-.033
22	.796	-.019	-.019	-.019	-.019	-.019	-.019	-.019	-.019	-.019	-.019	-.019	-.019	-.019
23	.861	-.007	-.008	-.008	-.008	-.008	-.008	-.008	-.008	-.008	-.008	-.008	-.008	-.008
24	.916	.116	.118	.117	.118	.118	.118	.118	.118	.118	.118	.118	.118	.118

	J=	14	15	16	17	18	19	20	21	22	23	24	25	26
PHASE,UEG=	24.5	85.5	91.5	97.5	103.5	109.5	115.5	121.5	127.5	133.5	139.5	145.5	151.5	
ALPHA,UEG=	.491	.484	.468	.457	.436	.416	.396	.376	.356	.336	.316	.296	.276	.256
I	x/C	*	*	*	*	*	*	*	*	*	*	*	*	*
1	.016	-.200	-.200	-.200	-.200	-.200	-.200	-.200	-.200	-.200	-.200	-.200	-.200	-.200
2	.067	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100
3	.092	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100
4	.117	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100	-.100
5	.142	-.097	-.097	-.097	-.097	-.097	-.097	-.097	-.097	-.097	-.097	-.097	-.097	-.097
6	.164	-.094	-.094	-.094	-.094	-.094	-.094	-.094	-.094	-.094	-.094	-.094	-.094	-.094
7	.191	-.091	-.091	-.091	-.091	-.091	-.091	-.091	-.091	-.091	-.091	-.091	-.091	-.091
8	.205	-.088	-.088	-.088	-.088	-.088	-.088	-.088	-.088	-.088	-.088	-.088	-.088	-.088
9	.240	-.085	-.085	-.085	-.085	-.085	-.085	-.085	-.085	-.085	-.085	-.085	-.085	-.085
10	.319	-.081	-.081	-.081	-.081	-.081	-.081	-.081	-.081	-.081	-.081	-.081	-.081	-.081
11	.343	-.078	-.078	-.078	-.078	-.078	-.078	-.078	-.078	-.078	-.078	-.078	-.078	-.078
12	.393	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074	-.074
13	.424	-.071	-.071	-.071	-.071	-.071	-.071	-.071	-.071	-.071	-.071	-.071	-.071	-.071
14	.470	-.067	-.067	-.067	-.067	-.067	-.067	-.067	-.067	-.067	-.067	-.067	-.067	-.067
15	.497	-.064	-.064	-.064	-.064	-.064	-.064	-.064	-.064	-.064	-.064	-.064	-.064	-.064
16	.547	-.061	-.061	-.061	-.061	-.061	-.061	-.061	-.061	-.061	-.061	-.061	-.061	-.061
17	.595	-.058	-.058											

TABLE 5.25. CONCLUDED.

	JA	27	28	29	30	31	32	33	34	35	36	37	38	39
PHASE, DEG	157.5	163.5	169.5	175.5	181.5	187.5	193.5	199.5	205.5	211.5	217.5	223.5	229.5	
ALPHA, DEG	-0.070	-0.086	-0.095	-0.090	-0.095	-0.087	-0.078	-0.057	-0.437	-0.413	-0.386	-0.355	-0.320	
1	.016	-.205	-.203	-.201	-.194	-.190	-.197	-.196	-.195	-.198	-.196	-.195	-.196	-.197
2	.057	-.103	-.100	-.097	-.094	-.092	-.090	-.089	-.088	-.086	-.086	-.087	-.087	-.088
3	.092	-.107	-.104	-.101	-.098	-.096	-.094	-.092	-.090	-.089	-.088	-.087	-.087	-.087
4	.117	-.102	-.100	-.097	-.094	-.092	-.090	-.088	-.086	-.084	-.083	-.085	-.085	-.085
5	.142	-.026	-.022	-.017	-.013	-.009	-.006	-.004	-.002	-.001	-.001	-.002	-.002	-.002
6	.164	-.037	-.035	-.029	-.026	-.023	-.021	-.019	-.016	-.014	-.014	-.013	-.013	-.013
7	.191	-.014	-.011	-.008	-.006	-.003	-.001	-.006	-.007	-.005	-.003	-.003	-.002	-.002
8	.245	-.941	-.937	-.931	-.927	-.922	-.919	-.915	-.912	-.908	-.906	-.904	-.903	-.902
9	.294	-.978	-.974	-.969	-.965	-.961	-.959	-.956	-.953	-.949	-.947	-.944	-.942	-.940
10	.319	-.991	-.988	-.985	-.980	-.977	-.974	-.972	-.969	-.965	-.963	-.959	-.957	-.955
11	.343	-.1005	-.1001	-.097	-.091	-.087	-.083	-.080	-.075	-.070	-.066	-.061	-.057	-.054
12	.393	-.102	-.097	-.092	-.086	-.080	-.074	-.068	-.062	-.054	-.046	-.038	-.030	-.020
13	.424	-.015	-.008	-.009	-.007	-.005	-.005	-.002	-.002	-.002	-.001	-.001	-.001	-.001
14	.470	-.918	-.901	-.874	-.833	-.804	-.767	-.744	-.798	-.601	-.802	-.804	-.806	-.806
15	.497	-.908	-.882	-.867	-.869	-.873	-.877	-.876	-.879	-.883	-.879	-.878	-.876	-.876
16	.547	-.1072	-.1070	-.1067	-.1063	-.1054	-.1040	-.1023	-.1007	-.984	-.960	-.941	-.939	-.932
17	.595	-.496	-.497	-.500	-.502	-.505	-.513	-.531	-.538	-.556	-.576	-.597	-.624	-.652
18	.616	-.629	-.631	-.637	-.642	-.645	-.640	-.649	-.678	-.691	-.692	-.650	-.526	-.538
19	.647	-.620	-.626	-.627	-.633	-.630	-.646	-.652	-.657	-.665	-.666	-.676	-.675	-.674
20	.667	-.353	-.353	-.359	-.363	-.366	-.371	-.375	-.378	-.377	-.381	-.384	-.383	-.383
21	.746	-.281	-.281	-.284	-.285	-.284	-.281	-.281	-.285	-.285	-.286	-.286	-.286	-.286
22	.790	-.110	-.111	-.111	-.113	-.113	-.115	-.115	-.115	-.117	-.117	-.117	-.119	-.119
23	.841	-.007	-.009	-.009	-.009	-.009	-.009	-.006	-.007	-.009	-.010	-.009	-.010	-.011
24	.891	-.127	-.134	-.135	-.136	-.135	-.134	-.134	-.130	-.124	-.123	-.130	-.129	-.129

	JA	40	41	42	43	44	45	46	47	48	49	50	51	52
PHASE, DEG	235.5	241.5	247.5	253.5	259.5	265.5	271.5	277.5	283.5	289.5	295.5	301.5	307.5	
ALPHA, DEG	-0.281	-0.240	-0.194	-0.167	-0.096	-0.046	0.069	0.062	0.110	0.167	0.216	0.263	0.307	
1	.016	-.197	-.194	-.201	-.204	-.208	-.207	-.200	-.211	-.214	-.217	-.219	-.222	-.225
2	.067	-.999	-.991	-.994	-.993	-.997	-.991	-.998	-.100	-.102	-.107	-.101	-.095	-.092
3	.092	-.1090	-.1090	-.1093	-.1095	-.1091	-.1091	-.1090	-.1088	-.1081	-.1078	-.1071	-.1061	-.1056
4	.117	-.1087	-.1088	-.1070	-.1074	-.1075	-.1076	-.1081	-.1084	-.1087	-.1091	-.1093	-.1097	-.1102
5	.142	-.000	-.001	-.003	-.005	-.007	-.011	-.015	-.019	-.024	-.029	-.033	-.038	-.043
6	.164	-.015	-.016	-.017	-.019	-.022	-.025	-.028	-.031	-.035	-.039	-.043	-.046	-.049
7	.191	-.993	-.993	-.995	-.994	-.999	-.992	-.996	-.1000	-.1010	-.1014	-.1016	-.1020	-.1023
8	.245	-.900	-.891	-.893	-.890	-.894	-.898	-.900	-.913	-.922	-.927	-.931	-.937	-.942
9	.294	-.930	-.930	-.930	-.930	-.943	-.944	-.944	-.957	-.956	-.959	-.962	-.968	-.973
10	.319	-.950	-.952	-.951	-.953	-.953	-.955	-.955	-.955	-.959	-.960	-.960	-.965	-.966
11	.343	-.951	-.953	-.953	-.945	-.945	-.945	-.945	-.951	-.955	-.955	-.956	-.957	-.958
12	.393	-.1000	-.946	-.923	-.905	-.888	-.868	-.845	-.823	-.802	-.782	-.762	-.742	-.722
13	.424	-.830	-.842	-.842	-.848	-.849	-.851	-.852	-.859	-.861	-.864	-.862	-.859	-.857
14	.467	-.607	-.607	-.606	-.606	-.623	-.624	-.624	-.627	-.626	-.626	-.626	-.627	-.627
15	.497	-.673	-.682	-.685	-.687	-.687	-.687	-.687	-.692	-.692	-.692	-.692	-.692	-.692
16	.537	-.684	-.686	-.686	-.686	-.683	-.682	-.682	-.685	-.686	-.686	-.686	-.686	-.686
17	.575	-.670	-.672	-.672	-.672	-.669	-.669	-.669	-.672	-.672	-.672	-.672	-.672	-.672
18	.610	-.537	-.539	-.532	-.532	-.532	-.532	-.532	-.532	-.532	-.532	-.532	-.532	-.532
19	.641	-.533	-.533	-.533	-.533	-.533	-.533	-.533	-.533	-.533	-.533	-.533	-.533	-.533
20	.672	-.530	-.530	-.530	-.530	-.530	-.530	-.530	-.530	-.530	-.530	-.530	-.530	-.530
21	.703	-.528	-.529	-.526	-.526	-.525	-.525	-.525	-.525	-.525	-.525	-.525	-.525	-.525
22	.734	-.519	-.519	-.519	-.519	-.519	-.519	-.519	-.519	-.519	-.519	-.519	-.519	-.519
23	.765	-.516	-.516	-.513	-.513	-.513	-.513	-.513	-.513	-.513	-.513	-.513	-.513	-.513
24	.815	-.127	-.127	-.126	-.126	-.126	-.126	-.126	-.126	-.126	-.126	-.126	-.126	-.126

	JA	53	54	55	56	57	58	59	60	61	62	63	64	65
PHASE, DEG	313.5	319.5	325.5	331.5	337.5	343.5	349.5	355.5	361.5	367.5	373.5	379.5	385.5	
ALPHA, DEG	-0.267	-0.235	-0.233	-0.235	-0.238	-0.242	-0.247	-0.252	-0.255	-0.260	-0.265	-0.270	-0.275	-0.280
1	.016	-.127	-.127	-.127	-.127	-.127	-.127	-.127	-.127	-.127	-.127	-.127	-.127	-.127
2	.057	-.123	-.123	-.123	-.123	-.123	-.123	-.123	-.123	-.123	-.123	-.123	-.123	-.123
3	.092	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.119	-.119
4	.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117	-.117
5	.142	-.116	-.116	-.116	-.116	-.116	-.116	-.116	-.116	-.116	-.116	-.116	-.116	-.116
6	.164	-.115	-.115	-.115	-.115	-.115	-.115	-.115	-.115	-.115	-.115	-.115	-.115	-.115
7	.191	-.114	-.114	-.114	-.114	-.114	-.114	-.114	-.114	-.114	-.114	-.114	-.114	-.114
8	.245	-.113	-.113	-.113</										

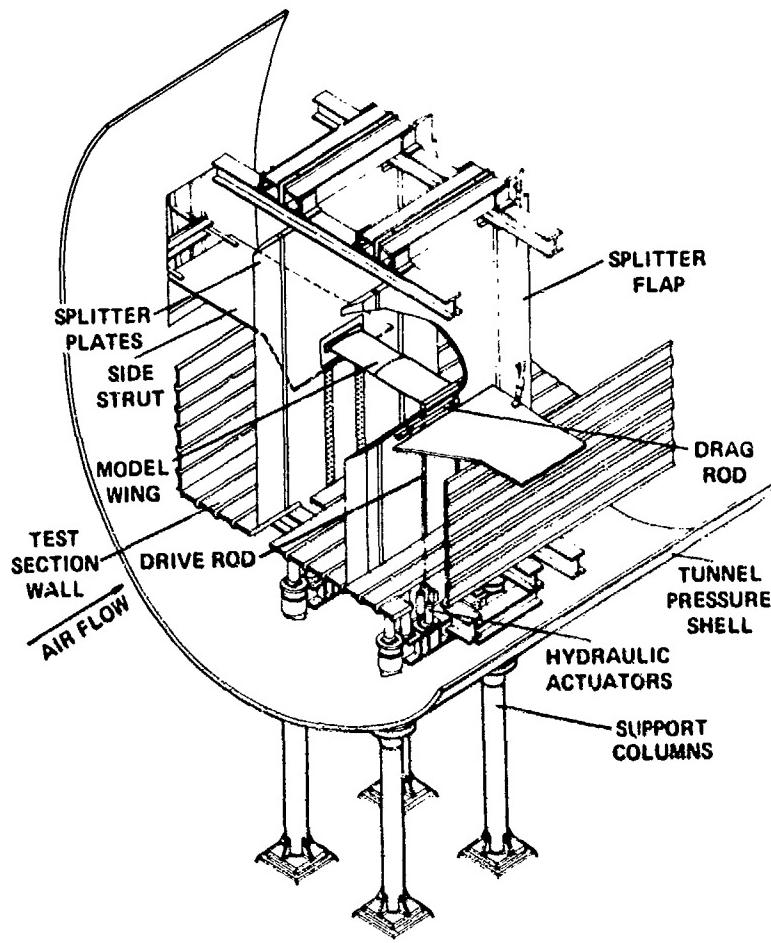


Fig. 5.1. General arrangement of oscillating airfoil test apparatus in NASA Ames 11- by 11-Foot Transonic Wind Tunnel.

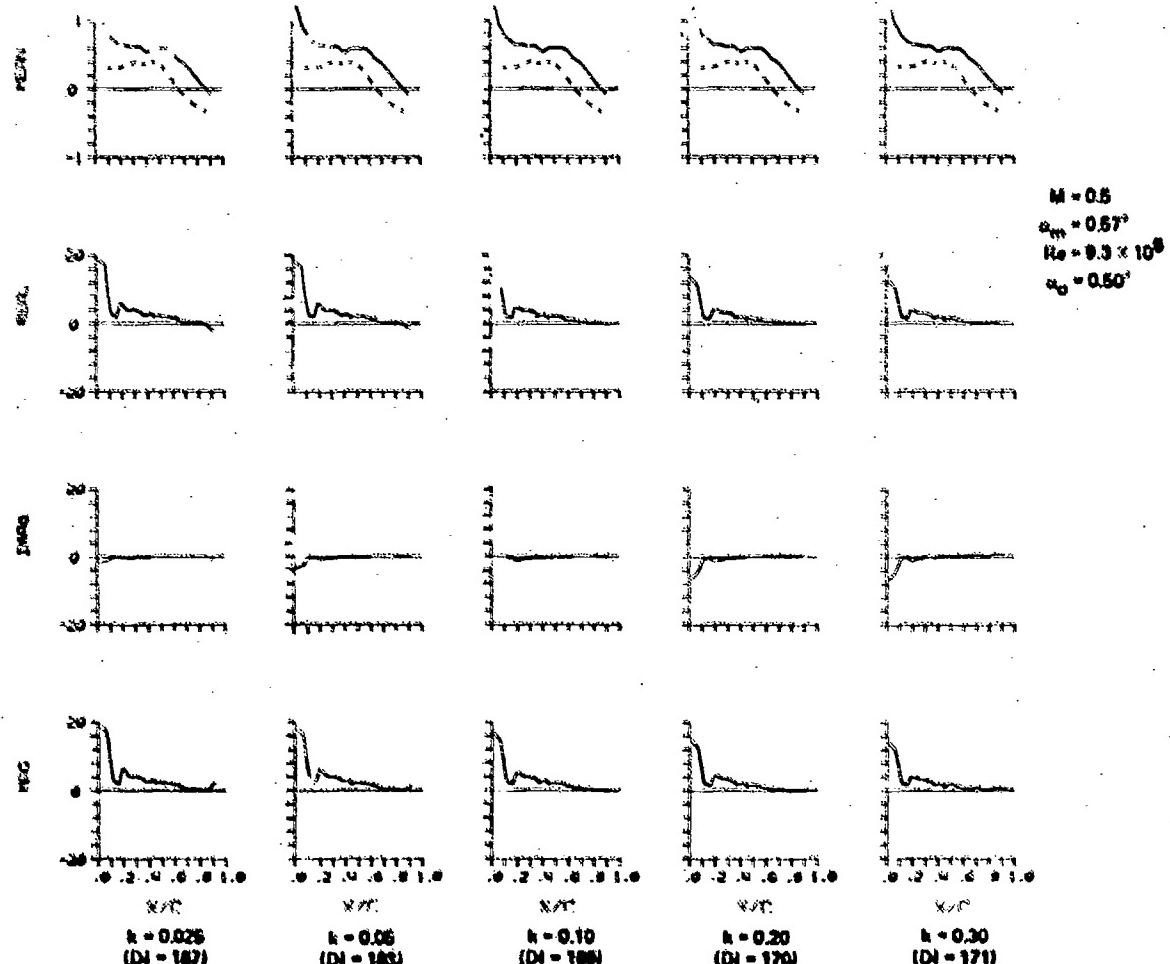


Fig. 5.2. Effect of varying frequency - subsonic flow.

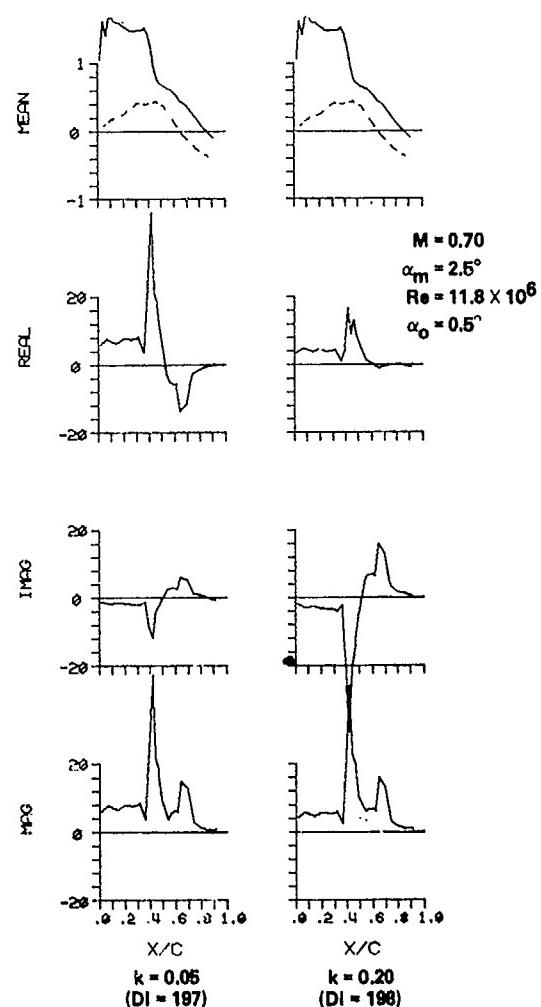


Fig. 5.3. Effect of varying frequency - transonic flow.

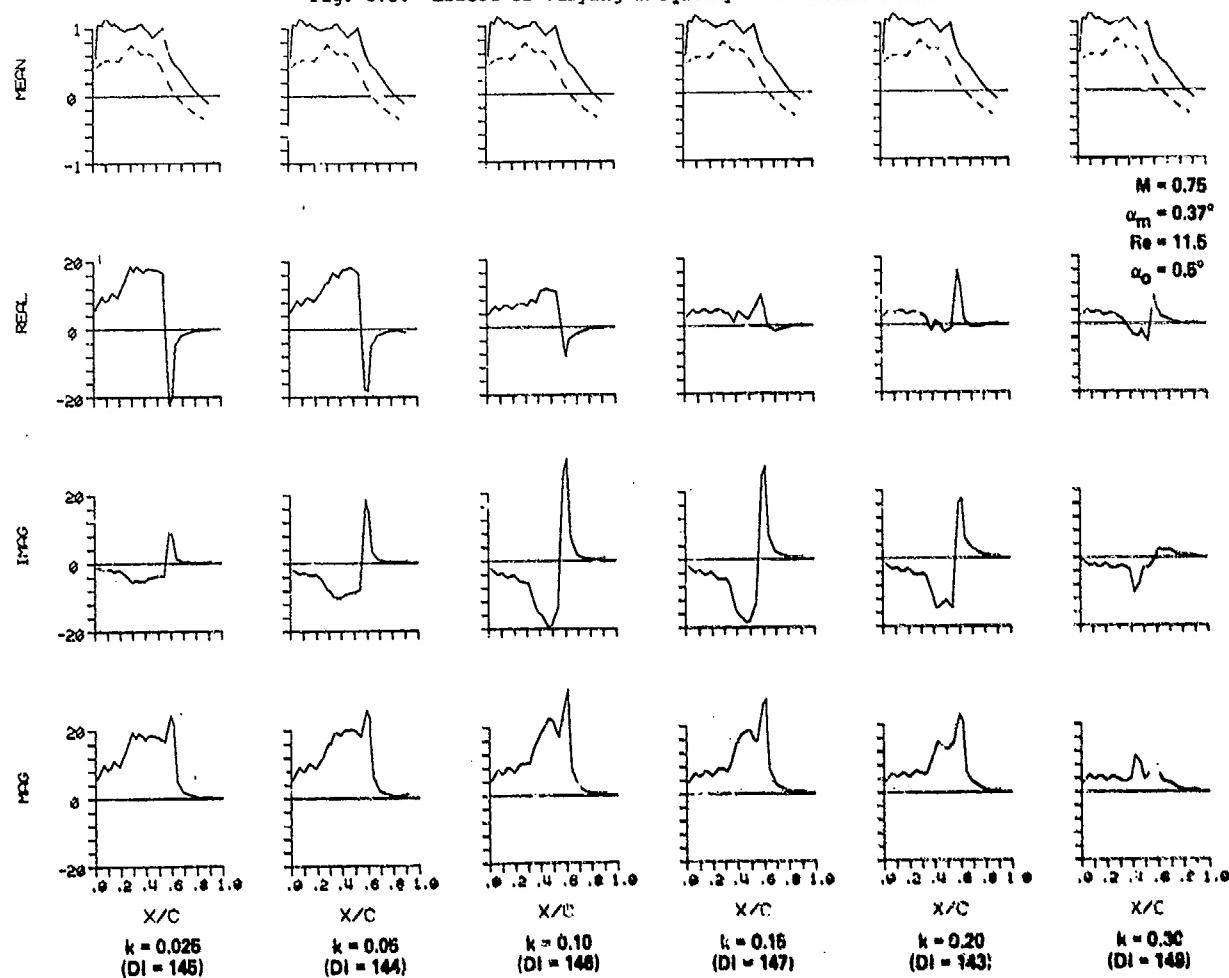


Fig. 5.4. Effect of varying frequency - supercritical design point.

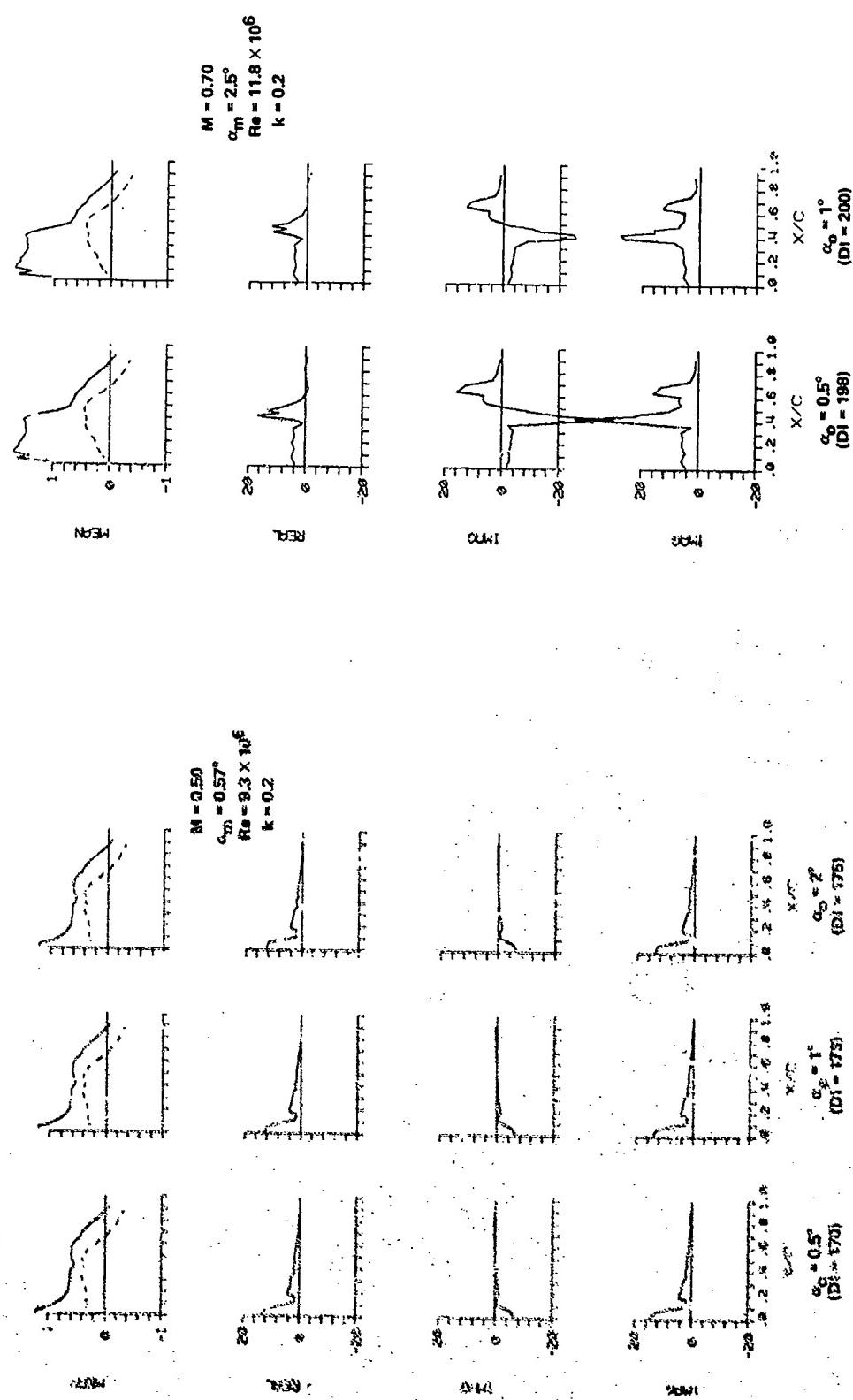


FIG. 5-2. Effect of varying amplitude - transonic flow.

Fig. 5-6. Effect of varying amplitude - transonic flow.

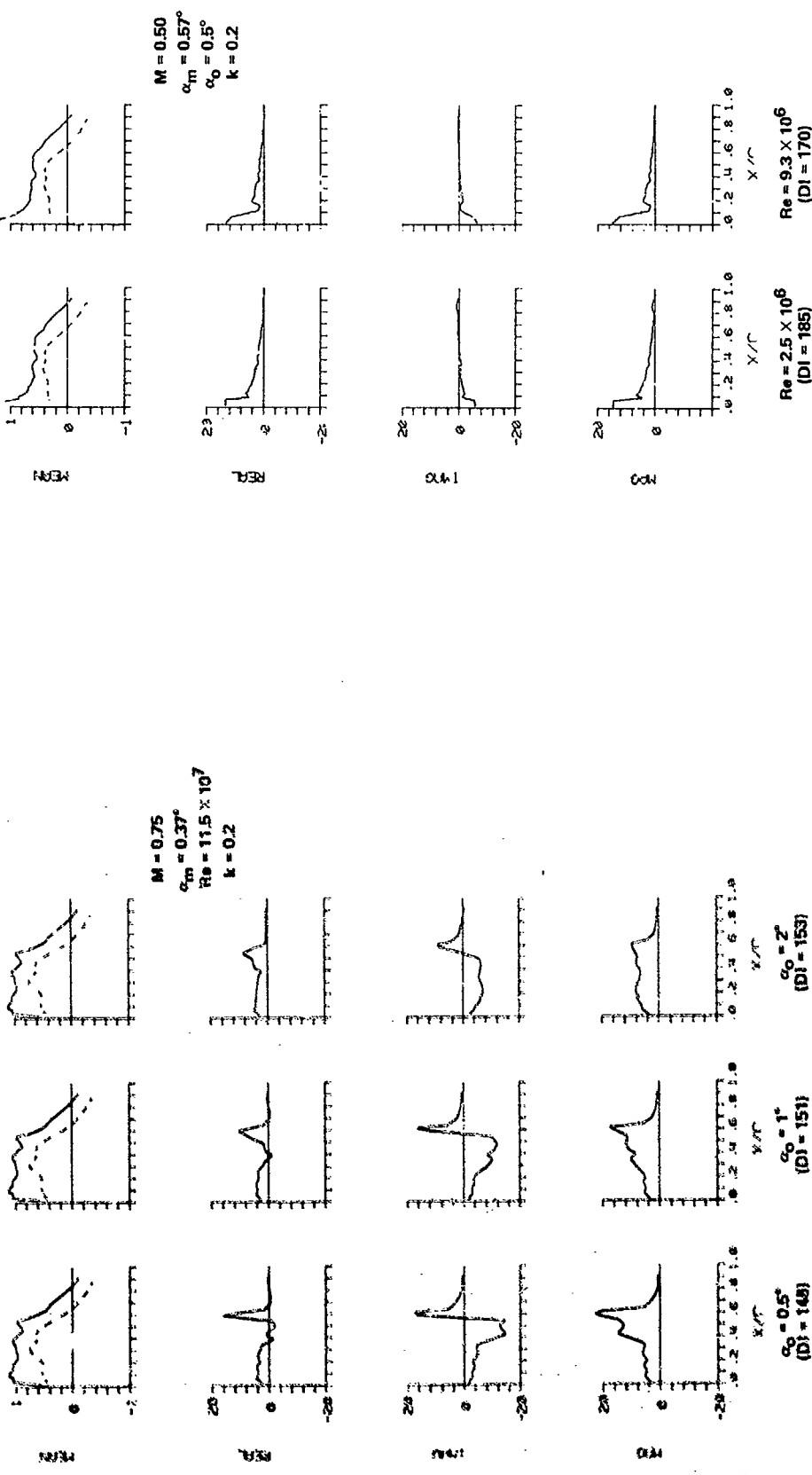


Fig. 5.8. Effect of varying Reynolds number - subsonic flow.

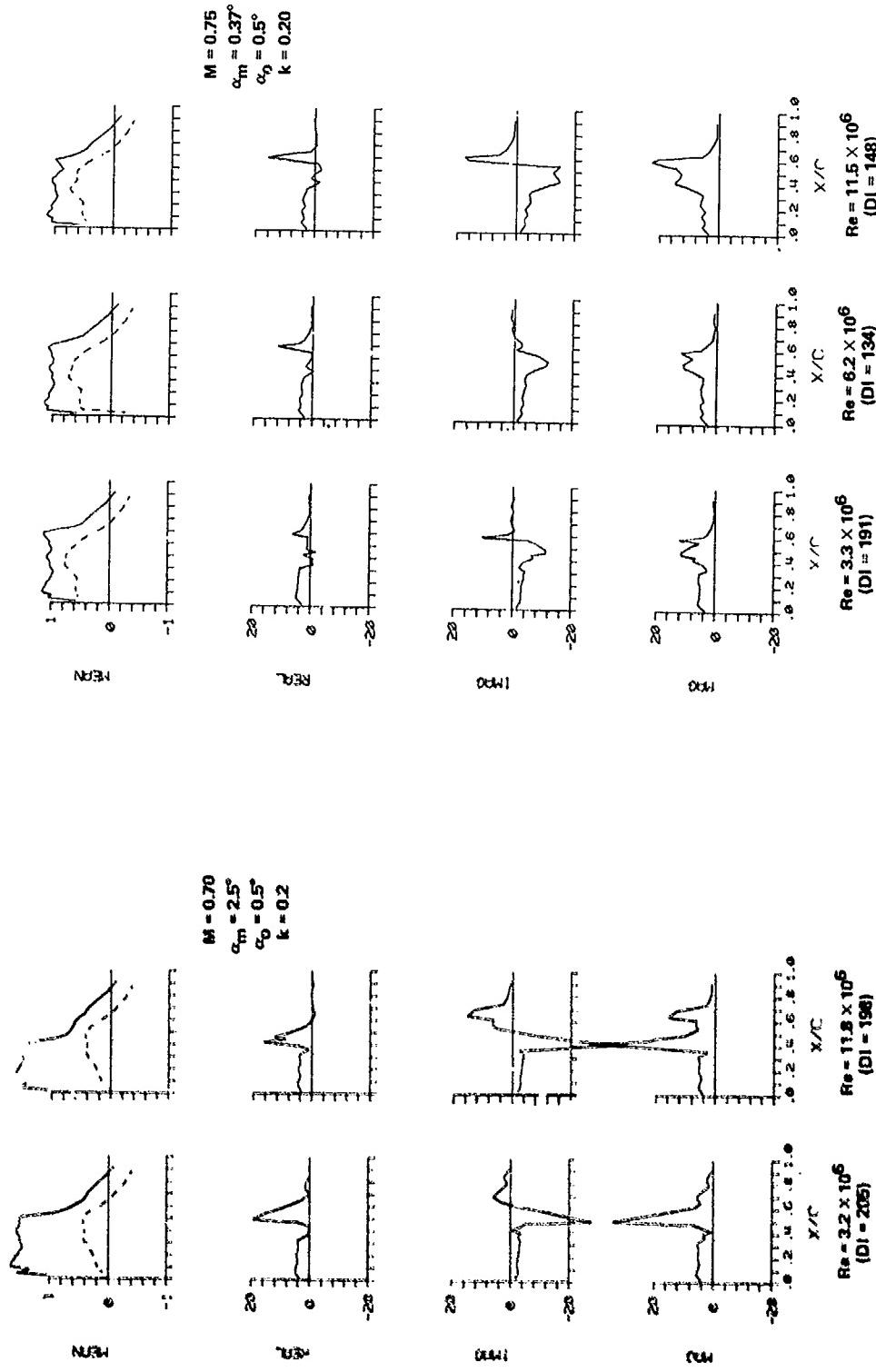


Fig. 5.9. Effect of varying Reynolds number - transonic flow.

Fig. 5.10. Effect of varying Reynolds number - supercritical design point.

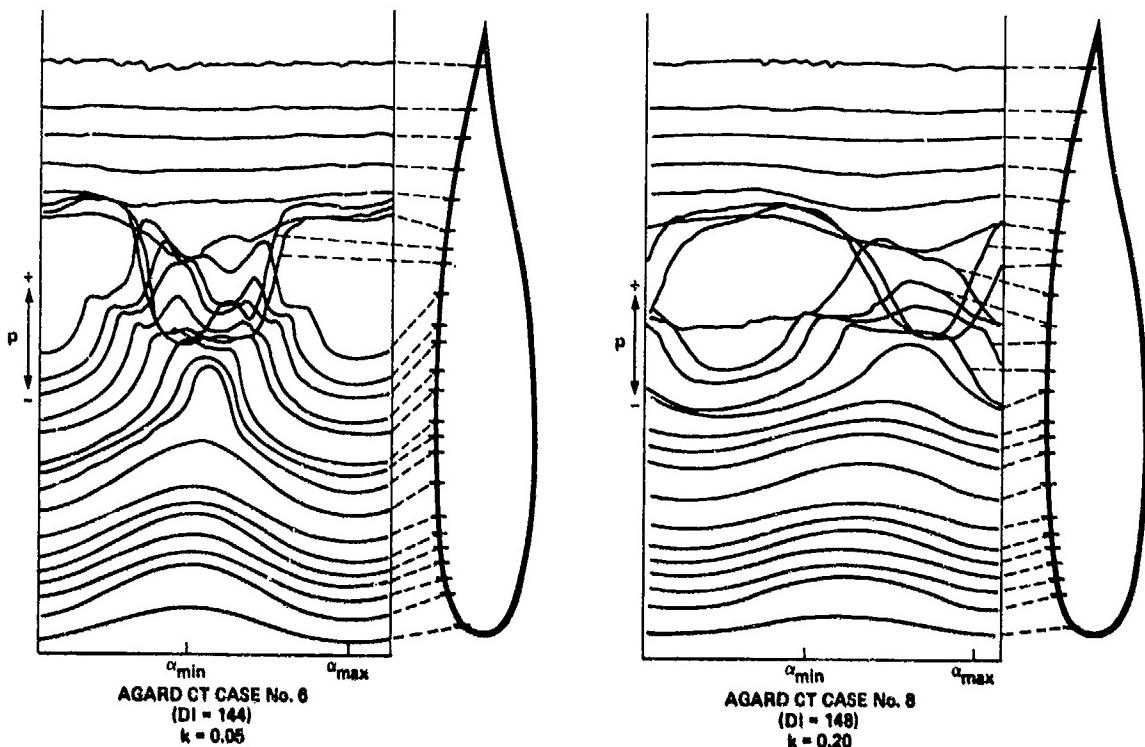


Fig. 5.11. Unsteady pressure time-histories for supercritical design case. $N = 0.721$, $\alpha_m = 0.19^\circ$.

DATA SET 6

RAE WING A. OSCILLATING FLAP

by

D. G. Mabey, RAE Bedford

INTRODUCTION AND DISCUSSION

An extensive series of oscillatory pressure measurements^{6.1,2} was made on a half model of a swept wing with a part-span trailing-edge flap (Fig 6.1), to highlight the uncertainties in linearised theory at transonic speeds and moderately high frequencies and to provide evidence of the importance of boundary-layer thickness. The model thickness-to-chord ratio was selected to ensure that at zero incidence, even at transonic Mach numbers up to $M = 0.9$, the local Mach number, M_e , would be less than 1.2, so that boundary-layer separations were avoided (Fig 6.2). The mean isomach contours are given in Figs 6.2 and 6.3 which illustrates some measurements made for angles of incidence other than zero.

The magnitude of the oscillatory pressures decreases significantly as the boundary-layer displacement thickness, δ_1 , at the flap hinge line increases, consistent with the reduced lift-curve slope of the flap. However, the phase lag of the oscillatory pressure with respect to the flap motion decreases as the boundary-layer thickness increases (Fig 6.4). This large change in phase angle, ϕ , is now attributed to the displacement effect of the time-dependent turbulent boundary layer^{6.3}.

The major uncertainty in the original experiment^{6.1,2} was the absolute value of the flap deflection, which could only be specified to about 5% accuracy because of aeroelastic distortion (both static and dynamic). In the subsequent tests a stiff flap was used made of carbon fibre^{6.3}, together with a new form of optical transducer to measure the flap amplitude^{6.4}. There were also improvements in the measurement of pressures. None of these measurements is included here, for other reasons discussed fully in Ref 6.3.

In the original experiment good comparisons with inviscid linearised theory were obtained at subsonic speeds (Fig 6.4). The principle of superposition of flap frequencies was valid at both subsonic and transonic speeds (Fig 6.5a&b). However, at transonic speeds sinusoidal flap movements do develop significant pressures at harmonic frequencies behind the shock waves, owing to the non-linearity of transonic flows^{6.1} and small aero-elastic distortions (Fig 6.6).

Ref 6.1 gives some details of the original experiment while Ref 6.2 reviews the principal results. Ref 6.3 gives some preliminary measurements on the same model fitted with a modified flap and drive system capable of much higher frequencies. Amongst other results, these tests established that in the original experiments^{6.1,2} the effects of the unwanted wing motion on the oscillatory pressures were small.

The data presented correspond with some of the CT cases in Ref 6.9 chosen for RAE Wing A with an oscillating flap and relate to both subsonic and transonic flows. Of the CT cases, 4 and 5 are for subcritical flow and 11 is for supercritical flow. For CT Cases 8 and 9 the unsteady flow is termed 'critical' because a local supersonic region is present intermittently. (See Table 6.1 and discussion in Ref 6.1.)

No data for the CT Cases with heaving or pitching or for CT Cases 10, 12 and 13 are yet available.

1 GENERAL DESCRIPTION OF MODEL

1.1 Designation	RAE Wing A
1.2 Type	Half model with part-span trailing-edge flap
1.3 Derivation	-
1.4 Additional remarks	-
1.5 References	Ref 6.5

2 MODEL GEOMETRY

2.1 Planform	Straight tapered
2.2 Aspect ratio	6
2.3 Leading-edge sweep	36.65°
2.4 Trailing-edge sweep	22.34°

2.5	Taper ratio	1/3
2.6	Twist	0
2.7	Root chord	240 mm
2.8	Span of model	s = 480 mm
2.9	Area of planform	0.0768 m ²
2.10	Location of reference sections and definition of profiles	RAE 101 - 9% streamwise
2.11	Lofting procedure between reference sections	Straight line generators
2.12	Form of wing-body, or wing-root junction	No body: 0.6 mm gap at root
2.13	Form of wing tip	Straight streamwise chord: no radius
2.14	Control surface details	Trailing-edge flap from n = 0.40 to 0.70. Hinge line at x/c = 0.70 swept 27.05°. Small chordwise and spanwise gaps (see Ref 6.1)
2.15	Additional remarks	-
2.16	References	-

3 WIND TUNNEL

3.1	Designation	RAE 3 ft × 3 ft
3.2	Type of tunnel	Continuous and pressurised
3.3	Test section dimensions	Height = 640 mm, width = 910 mm, length = 1370 mm
3.4	Type of roof and floor	Slotted
3.5	Type of side walls	Closed
3.6	Ventilation geometry	Four complete slots and two corner half slots in roof and floor, covered with perforated plates. Open area ratio of slots = 8%
3.7	Thickness of side wall boundary layer	$\delta^* = 7$ mm
3.8	Thickness of boundary layers at roof and floor	δ^* less than 7 mm
3.9	Method of measuring Mach number	Plenum chamber pressure
3.10	Flow angularity	About 0.1°
3.11	Uniformity of Mach number over test section	±0.002
3.12	Sources and levels of noise or turbulence in empty tunnel	Mixing region at ends of working section. Typical levels at transonic speeds $\sqrt{n} F(n) =$ 0.004 (Ref 6.6)
3.13	Tunnel resonances	Tunnel resonance frequencies well above flap frequencies
3.14	Additional remarks	-
3.15	References on tunnel	Ref 6.6

4 MODEL MOTION

4.1	General description	Sinusoidal pitching of flap about swept hinge line
4.2	Reference coordinate and definition of motion	Flap deflection relative to wing chord at $n = 0.55$ (mid-flap)
4.3	Range of amplitude	0 to 2°

4.4	Range of frequency	0, 1 Hz, 90 Hz and limited data available at 131 Hz
4.5	Method of applying motion	Semi-resonant motion
4.6	Timewise purity of motion	Good. First overtone 40 dB lower than fundamental
4.7	Natural frequencies and normal modes of model and support system	First bending frequency at 60 Hz, second bending frequency at 143 Hz, minimum model motion at 90 Hz
4.8	Actual mode of applied motion including any elastic deformation	Elastic deformations were not measured but were subsequently shown not to alter the pressures at 1 and 90 Hz
4.9	Additional remarks	Influence of wing motion discussed in Ref 6.3
5	TEST CONDITIONS	
5.1	Model planform area/tunnel area	0.13
5.2	Model span/tunnel width	0.53
5.3	Blockage	1.2%
5.4	Position of model in tunnel	685 mm from start of working section
5.5	Range of Mach number	0.40, 0.65, 0.80, 0.85, 0.90, 0.95
5.6	Range of tunnel total pressure	0.95 bar
5.7	Range of tunnel total temperature	278 K to 298 K
5.8	Range of model steady, or mean, incidence	0 to 2°
5.9	Definition of model incidence	Model set to zero geometric incidence (NB up to 0.1° flow deflection)
5.10	Position of transition, if free	Limited data with free transition in Ref 6.2
5.11	Position and type of trip, if transition fixed	x/c = 0.05, roughness elements 0.13 mm high and 2 mm apart
5.12	Flow instabilities during tests	No periodic shock oscillation but some random oscillation associated with unsteadiness in tunnel flow
5.13	Changes to mean shape of model due to steady aerodynamic load	Negligible
5.14	Additional remarks	-
5.15	References describing tests	Refs 6.1, 6.2
6	MEASUREMENTS AND OBSERVATIONS	
6.1	Steady pressures for the mean conditions	/
6.2	Steady pressures for small changes from the mean conditions	-
6.3	Quasi-steady pressures	/
6.4	Unsteady pressures	/
6.5	Steady section forces for the mean conditions by integration of pressures	-
6.6	Steady section forces for small changes from the mean conditions by integration	-
6.7	Quasi-steady section forces by integration	-
6.8	Unsteady section forces by integration	-
6.9	Measurement of actual motion at points on model	-

- 6.10 Observation or measurement of boundary layer properties
- 6.11 Visualization of surface flow
- 6.12 Visualization of shockwave movements
- 6.13 Additional remarks

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✓
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7

INSTRUMENTATION

7.1 Steady pressures

- 7.1.1 Position of orifices spanwise and chordwise
- 7.1.2 Type of measuring system

See data tables

Capsule manometers

7.2 Unsteady pressures

- 7.2.1 Position of orifices spanwise and chordwise
- 7.2.2 Diameter of orifices
- 7.2.3 Type of measuring system
- 7.2.4 Type of transducers
- 7.2.5 Principle and accuracy of calibration

See data tables

0.5 mm

Individual in situ transducers

Kulite type XCQL 093 25A

Steady calibration and tests with oscillatory pressure generator (see Ref 6.7)

7.3 Model motion

- 7.3.1 Method of measuring motion reference coordinates
- 7.3.2 Method of determining spatial mode of motion
- 7.3.3 Accuracy of measured motions

Foil strain gauges on steel flexures at $n = 0.52$ and 0.66 . Average motion at $n = 0.55$

Not measured

5%

7.4 Processing of unsteady measurements

- 7.4.1 Method of acquiring and processing measurements
- 7.4.2 Type of analysis
- 7.4.3 Unsteady pressure quantities obtained and accuracies achieved
- 7.4.4 Method of integration to obtain forces

Serial logger to Digital Transfer Function Analyser (DTFA); paper tape input to remote computer; parallel magnetic tape

Harmonic

Fundamental only

Not integrated

-

Refs 6.1, 6.3 and 6.4

8. DATA PRESENTATION

- 8.1 Test cases for which data could be made available
- 8.2 Test cases for which data are included in this document
- 8.3 Steady pressures
- 8.4 Quasi-steady or steady perturbation pressures
- 8.5 Unsteady pressures
- 8.6 Steady forces or moments
- 8.7 Quasi-steady or steady perturbation forces
- 8.8 Unsteady forces and moments
- 8.9 Other forms in which data could be made available

Table 6.1

Table 6.1

Tables 6.2 to 6.5

Tables 6.2 to 6.5

Tables 6.2 to 6.5

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8.10	References giving other presentations of data	Refs 6.1, 6.2, 6.3 and 6.8
9 COMMENTS ON DATA		
9.1	Accuracy	
9.1.1	Mach number	± 0.002
9.1.2	Steady incidence	$\pm 0.1^\circ$
9.1.3	Reduced frequency	Variations up to $\pm 2\%$ from nominal values due to temperature variations
9.1.4	Steady pressure coefficients	C_p better than ± 0.006
9.1.5	Steady pressure derivatives	-
9.1.6	Unsteady pressure coefficients	Magnitude of \bar{C}_p/δ_0 to $\pm (0.05 \bar{C}_p/\delta_0 + 0.02)$. Phase to $\pm 30^\circ$.
9.2	Sensitivity to small changes of parameter	-
9.3	Non-linearities	Small (discussed in Refs 6.1 and 6.2)
9.4	Influence of tunnel total pressure	Not known
9.5	Effects on data of uncertainty, or variation, in mode of model motion	See Introduction
9.6	Wall interference corrections	None
9.7	Other relevant tests on <u>same model</u>	Ref 6.3
9.8	Relevant tests on other models of nominally the <u>same shape</u>	Ref 6.5 for relevant steady tests
9.9	Any remarks relevant to comparison between experiment and theory	Some interesting comparisons with subsonic inviscid linearised theory in Ref 6.2
9.10	Additional remarks	-
9.11	References on discussion of data	Refs 6.1, 6.2 and 6.3
10	PERSONAL CONTACT FOR FURTHER INFORMATION	D.G. Mabey Dynamics Laboratory RAE Bedford MK41 6AE UK
11	LIST OF REFERENCES	
6.1	D.M. McOwat B.L. Welsh B.E. Cripps	Time-dependent pressure measurements on a swept wing with an oscillating trailing-edge flap. RAE Technical Report 81033 (1981)
6.2	D.G. Mabey B.L. Welsh D.N. McOwat	Aerodynamic characteristics of moving trailing-edge controls at subsonic speeds. AGARD CP 262, Paper 20, May 1979; RAE Technical Memorandum Structures 947 (1979)
6.3	D.G. Mabey B.L. Welsh B.E. Cripps	Further aerodynamic characteristics of moving trailing-edge controls at subsonic and transonic speeds. RAE Technical Report 80134 (1980)
6.4	B.L. Welsh	A new angular displacement transducer. RAE Technical Report 79026 (1979)
6.5	D.A. Treadgold A.P. Jones K.H. Wilson	Pressure distribution measured in the RAE 8ft x 6ft transonic tunnel on RAE Wing 'A' in combination with an axisymmetric body at Mach numbers of 0.4, 0.8 and 0.9. AGARD AR 138, Paper B4 (1979)

- 6.6 D.G. Mabey Flow unsteadiness of model vibration in wind tunnels at subsonic and transonic speeds.
CP 1155 (1971)
- 6.7 B.L. Welsh Some notes on the measurement of oscillatory pressures.
RAE Technical Memorandum Structures 869 (1975)
- 6.8 D.M. McOwat Dynamics Lab Memo 1 (1982)
- 6.9 S.R. Bland AGARD three-dimensional aeroelastic configurations.
AGARD-AR-167 (1982)

12 NOTATION

c_r	root chord
C_p	steady pressure coefficient
\bar{C}_p	complex pressure coefficient
$R(\bar{C}_p)$	real part of \bar{C}_p
$I(\bar{C}_p)$	imaginary part of \bar{C}_p
f	frequency (Hz)
k	frequency parameter $f=c_r/U$
M	free stream Mach number
M_e	local external Mach number
Re	Reynolds number based on free stream conditions and root chord
U	free stream velocity
α	angle of incidence
δ_0	flap amplitude in streamwise direction (see Note below)
δ_1	boundary-layer displacement thickness at hinge line
δ^*	boundary-layer displacement thickness at wall
n	dimensionless spanwise coordinate y/s
Λ	sweepback angle
ζ	dimensionless chordwise coordinate (fraction of local chord)
ϕ	phase angle of pressure with respect to flap motion

NOTE: For consistency with the standard notation suggested by Bland, the symbol δ represents the flap deflection angle measured streamwise. In Refs 6.1 to 6.3, which give other information about the tests, the symbol δ' represents the flap deflection measured normal to the hinge line. Thus

$$\begin{aligned} (\delta, \text{ as used here}) &= (\delta \text{ of Refs}) \times \cos \Lambda_{HL}, \quad \text{where } \Lambda_{HL} = 27.05^\circ \\ &= (\delta \text{ of Refs}) \times 0.891. \end{aligned}$$

$$(\bar{C}_p/\delta, \text{ as used here}) = (\bar{C}_p/\delta \text{ of Refs}) \times 1.122.$$

Table 6.1
SUMMARY OF DATA GIVEN AND DATA AVAILABLE

M	$Re \times 10^{-6}$	k	δ_0 (deg)	α (deg)	n				CT or data given	Time- dependent flow	Test No.	
					0.35	0.45	0.60	0.75				
0.40	1.91	Steady	-	0	1	1	1	1				
		0.0055	1.78	0	1	1	1	0		A	1	
		0.50	1.71	0	1	1	1	1		A		
0.65	2.78	Steady	-	0	1	1	1	1				
		0.0035	1.75	0	1	1	1	0		A	2	
		0.32	1.63	0	1	1	1	1		A		
0.80	3.14	Steady	-	+2 +1 0 -1 -2	1 1 1 1 1	1 1 1 0 1	1 1 1 1 1	1 1 1 0 1	/		9	
		0.0029	1.75	+2 +1 0 -1 -2	1 0 1 0 1	1 1 1 1 1	1 0 1 0 1	0 0 0 0 0	/	A	9	
		0.26	1.60	+2 +1 0 -1 -2	1 1 1 1 1	1 1 1 0 1	1 1 1 1 1	1 1 1 1 1	-	A	7	
									/	A	3	
									-	A	8	
									/	A	10	
		0.0028	1.75	+2 +1 0 -1 -2	1 0 1 0 1	1 1 1 1 1	1 1 1 1 1	0 0 0 0 0		B	13	
		0.25	1.58	+2 +1 0 -1 -2	1 1 1 1 1	1 1 1 1 1	1 1 1 1 1	1 1 1 1 1		A	11	
		0.90	3.32	Steady	-	+1 0 -1	1 1 1	1 1 1	1 1 1	/		13
		0.0026	1.76	+1 0 -1	0 1 0	1 1 1	1 1 1	0 0 0	/	C	15	
		0.24	1.58	+1 0 -1	1 1 1	1 1 1	1 1 1	1 1 1	8	B	5	
		0.95	3.38	Steady	-	+1 0 -1	1 1 1	1 1 1	1 1 1	/		16
		0.0036	1.80	+1 0 -1	0 1 0	1 1 1	1 1 1	0 0 0		C	16	
		0.23	1.58	+1 0 -1	1 1 1	1 1 1	1 1 1	1 1 1		C	17	
										C	6	
										C	18	

Type of flow: A Subcritical
B Critical
C Supercritical

Data available: 1
No data: 0
Data given: /

All tests made with fixed transition.
Results for lower surface are obtained from negative incidences.

Table 6.2

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Table 6.3

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Table 6.3 (concluded)

CASE 5

Test	M_{35}	α	δ_0	Surface	$k = 2.9 \times 10^{-3}$	f
10	$1.75(E=1)$		lower			
	$1.60(E=90)$					
$\eta = .35$						
f	data	ξ	$.812$	$.825$	$.8799$	$.8199$
-	CP/Co	$.815$	$.822$	$.8234$	$.8158$	$.8111$
1.	$.89R(CP/Co)$	$.835$	$.843$	$.8783$	$.8138$	$.8116$
99.	$.8911(CP/Co)$	$.838$	$.8519$	$.87819$	$.8112$	$.8186$
		$.8162$	$.8153$	$.8142$	$.8159$	$.8115$
		$.8162$	$.8153$	$.8142$	$.8159$	$.8115$
f	data	ξ	$.812$	$.826$	$.8799$	$.8199$
-	CP/Co	$.8264$	$.8394$	$.8551$	$.8213$	$.8247$
1.	$.89R(CP/Co)$	$.8372$	$.8564$	$.8751$	$.8213$	$.8247$
99.	$.8911(CP/Co)$	$.8451$	$.8662$	$.8751$	$.8156$	$.8215$
		$.8231$	$.8269$	$.8214$	$.8283$	$.8191$
$\eta = .45$						
f	data	ξ	$.812$	$.824$	$.8799$	$.8198$
-	CP/Co	$.8259$	$.8485$	$.8651$	$.8132$	$.8231$
1.	$.89R(CP/Co)$	$.8352$	$.8556$	$.8751$	$.8173$	$.8264$
99.	$.8911(CP/Co)$	$.8451$	$.8662$	$.8751$	$.8156$	$.8215$
		$.8231$	$.8269$	$.8214$	$.8283$	$.8191$
$\eta = .55$						
f	data	ξ	$.812$	$.824$	$.8798$	$.8198$
-	CP/Co	$.8259$	$.8485$	$.8651$	$.8132$	$.8231$
1.	$.89R(CP/Co)$	$.8352$	$.8556$	$.8751$	$.8173$	$.8264$
99.	$.8911(CP/Co)$	$.8451$	$.8662$	$.8751$	$.8156$	$.8215$
		$.8231$	$.8269$	$.8214$	$.8283$	$.8191$
$\eta = .75$						
f	data	ξ	$.812$	$.824$	$.8798$	$.8198$
-	CP/Co	$.8331$	$C.8223$	$.8446$	$.8216$	$.8238$
1.	$.89R(CP/Co)$	$.8386$	$.8586$	$.8786$	$.8186$	$.8286$
99.	$.8911(CP/Co)$	$.8478$	$.8686$	$.8786$	$.8186$	$.8286$
		$.8231$	$.8269$	$.8214$	$.8283$	$.8191$

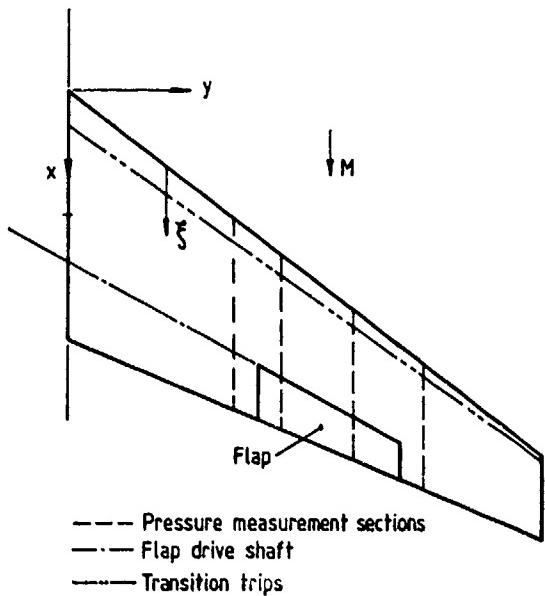
Table 6

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Table 6.5 (concluded)

CASE II

Test	n	α	δ_0	Surface	$k = 2.7 \times 10^{-3}$	ϵ
16	6.95	1.0	1.76($\epsilon=1$)	lower		
			1.58($\epsilon=90$)			
$\eta = 0.25$						
ϵ	data	ζ	0.812	0.825	0.849	0.899
-			0.815	0.824	0.831	0.899
1.	$\zeta^{p/5}$	$\zeta^{p/5}$	0.818	0.828	0.835	0.895
95.	$\zeta^{p/5}(\zeta^{p/5})^2$	$\zeta^{p/5}(\zeta^{p/5})^2$	0.826	0.836	0.843	0.893
			0.828	0.838	0.843	0.893
$\eta = 0.45$						
ϵ	data	ζ	0.812	0.826	0.849	0.899
-			0.813	0.825	0.831	0.899
1.	$\zeta^{p/5}$	$\zeta^{p/5}$	0.813	0.825	0.831	0.899
95.	$\zeta^{p/5}(\zeta^{p/5})^2$	$\zeta^{p/5}(\zeta^{p/5})^2$	0.813	0.825	0.831	0.899
			0.813	0.825	0.831	0.899
$\eta = 0.65$						
ϵ	data	ζ	0.812	0.824	0.849	0.899
-			0.815	0.826	0.831	0.899
1.	$\zeta^{p/5}$	$\zeta^{p/5}$	0.818	0.830	0.834	0.895
95.	$\zeta^{p/5}(\zeta^{p/5})^2$	$\zeta^{p/5}(\zeta^{p/5})^2$	0.821	0.837	0.842	0.892
			0.821	0.837	0.842	0.892
$\eta = 0.75$						
ϵ	data	ζ	0.812	0.824	0.848	0.898
-			0.815	0.826	0.831	0.898
1.	$\zeta^{p/5}$	$\zeta^{p/5}$	0.818	0.830	0.834	0.895
95.	$\zeta^{p/5}(\zeta^{p/5})^2$	$\zeta^{p/5}(\zeta^{p/5})^2$	0.822	0.837	0.842	0.895



— Pressure measurement sections
— Flap drive shaft
— Transition trips

Aspect ratio	AR	6
Taper ratio	λ	$1/3$
Section		RAE 101
Thickness/chord ratio	t/c	0.09
Sweepback:		
Leading edge	$\Lambda(0)$	36.65°
Mid-chord	$\Lambda(0.5)$	30.00°
Flap LE	$\Lambda(0.7)$	27.05°
Trailing edge	$\Lambda(1.0)$	22.33°
Semi-span	s	0.48m
Root chord	c_r	0.24m
First mean chord	\bar{c}	0.16m
Wing area	$S/2$	0.0768m ²
Flap Span		0.4×0.7
Chord		0.7×0.16
Transition trips:		
Position	ξ	0.05
Height		0.127mm

Fig 6.1 Model geometry: RAE Wing A

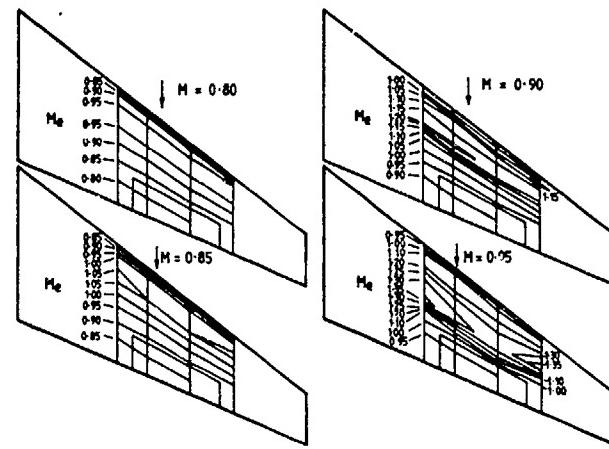


Fig 6.2 Mean isomach contours: $\alpha = 0$

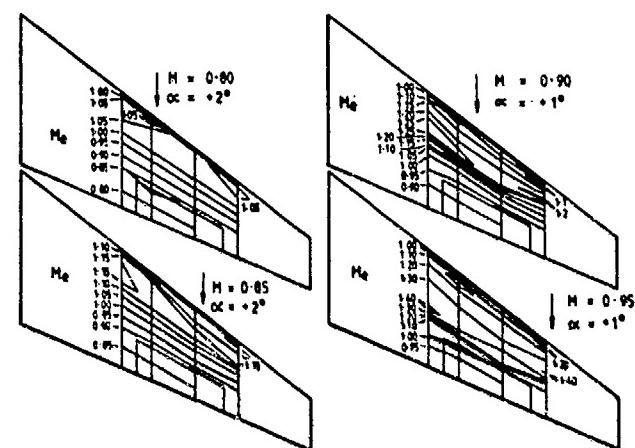


Fig 6.3 Mean isomach contours: suction surface

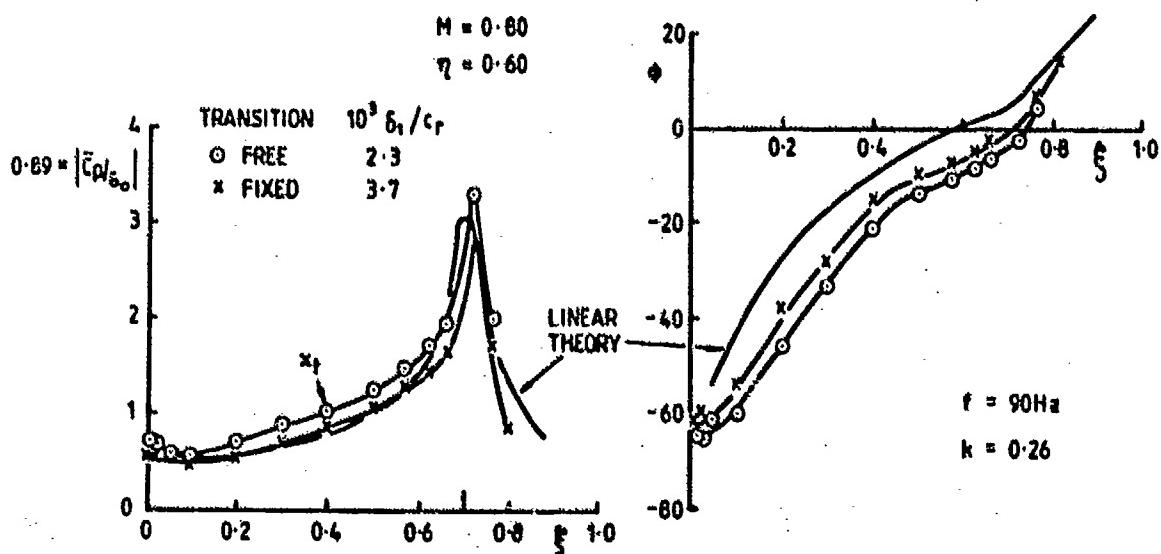


Fig 6.4 Magnitude and phase of subsonic pressure distribution

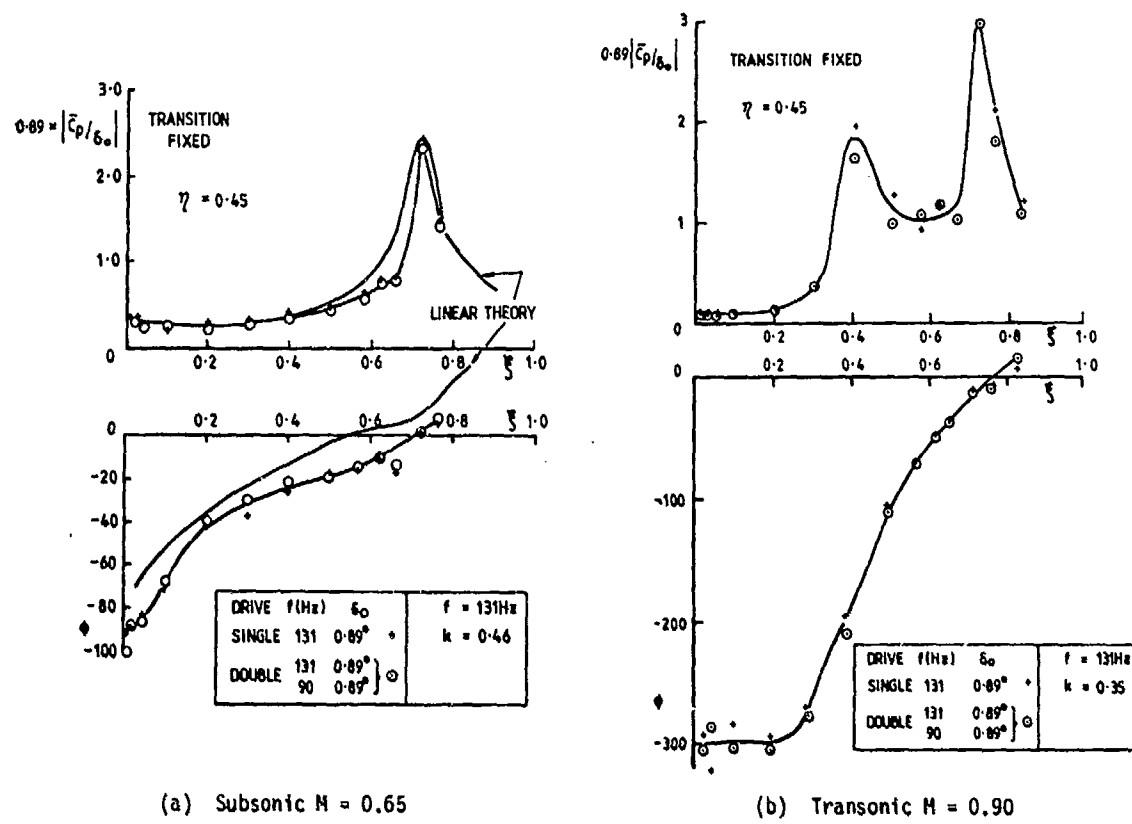
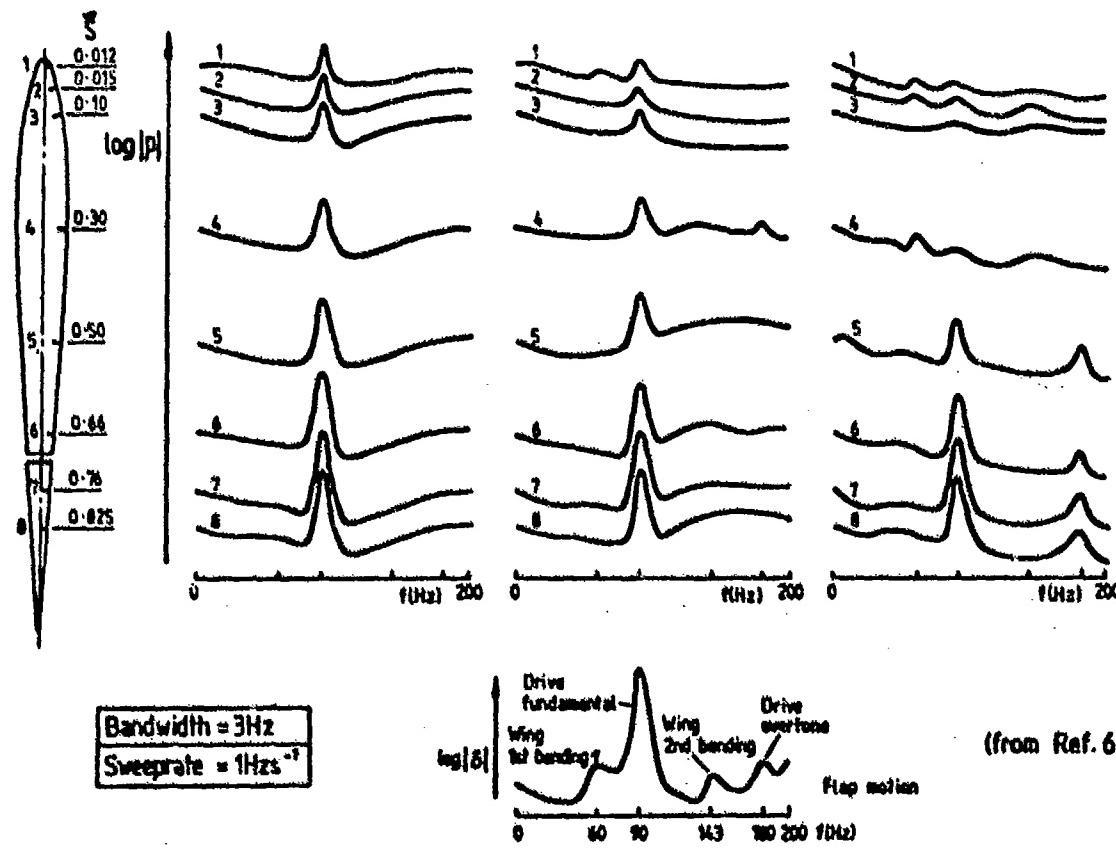
(a) Subsonic $M = 0.65$ (b) Transonic $M = 0.90$

Fig 6.5 Superposition of two frequencies

(a) Subcritical: $M = 0.85$ (b) Critical: $M = 0.90$ (c) Supercritical: $M = 0.95$ Fig 6.6 Typical spectra: $\alpha = 0$, $n = 0.60$

DATA SET 7

NORA MODEL. OSCILLATION ABOUT A SWEPT AXIS

by

N. C. Lambourne (formerly with RAE)

INTRODUCTION

This Data Set relates to a low-aspect-ratio model oscillating as a rigid body about a sweptback axis as shown in Fig 7.1. The data were obtained during an international cooperative investigation of wind-tunnel interference on unsteady measurements*. Comparative measurements were made in four different tunnels two of which, the NLR High Speed Tunnel (HST) and the ONERA Modane S2 tunnel, were large in comparison with the model. The results from those tunnels are considered to be free of large interference effects.

The numerical data included here correspond closely with the AGARD CT Cases and come mainly from the HST in which the most extensive tests were made. Where nominally identical conditions were tested in the S2 tunnel, the corresponding data from that source are also included.

Fig 7.2 and Table 7.1 show the parametric combinations for which data could be made available if required. The cases for which data are included here are detailed in Table 7.2; they comprise not only all the CT Cases, but in addition a low-frequency (5 Hz) set of data for every Mach number and mean incidence combination of the CT Cases.

Fig 7.1 and Table 7.3 show the positions at which the steady and unsteady pressures were measured. Because no steady pressures were obtained at the two spanwise positions at which the oscillatory pressures were measured, direct comparisons between unsteady and zero-frequency ($k = 0$) equivalents are not possible. However, oscillatory pressures were measured for an oscillation frequency of 5 Hz ($k \approx 0.035$) and it is considered that the in-phase component of pressure for this frequency is sufficiently close to that which would be obtained for a quasi-steady condition, $k \rightarrow 0$.

For the unsteady measurements, attention was directed mainly to the upper surface (the extrados, denoted throughout by E) whilst only a few measuring positions were provided at the lower surface (the intrados denoted by I).

It should be noted that the measured steady pressures are not expressed as pressure coefficients C_p , but as local Mach numbers M_L . Also the oscillatory pressures have not been converted from their original form of R and I , the real and imaginary components non-dimensionalised using tunnel total pressure, and not dynamic pressure. Multiplying factors for the conversion of these quantities to the more usual $C'_p/0$ and $C''_p/0$ are included in the tables.

Mode of oscillation

The oscillation imposed on the model was basically rigid-body rotation about the axis shown in Fig 7.1. The motion was defined by the output of a transducer attached to the driving shaft rigidly fixed to the root of the model. The transducer output was calibrated to read angular displacement θ in a streamwise plane parallel to the plane $y = 0$. The oscillatory signal, $\theta = \theta_0 \sin \omega t$, acted as a phase and amplitude reference for all the other oscillatory quantities.

Due to model flexibility, there were slight departures from the design mode of rigid-body motion, and these differences tended to increase with oscillation frequency. Information about the actual motion was obtained from the six accelerometers installed within the model as shown in Fig 7.1 and detailed in Table 7.4.

Because displacements deduced from accelerometers tend to be unreliable for low frequencies, no measurements were made for 5 Hz. However, for this frequency it can be confidently concluded that the differences between the actual motion and the design mode were negligible.

For the 40 Hz tests corresponding to the CT Cases, the complex amplitudes of the normal displacements, z , at each of the accelerometer positions are given in Table 7.5. The severity of the departures from the design mode is more readily appreciated from Table 7.6 which gives, for the three spanwise positions containing accelerometers, local pitching and wing bending (i.e. the rotation about, and the normal displacements of, the design axis) as deduced on the basis that each chordwise section remains rigid. Not surprisingly, the deformations in twist and bending tend to increase with spanwise position.

* The letters of the acronym NORA refer to the names of the organisations involved: NLR, ONERA, RAE and AVA (a branch of DFWLR).

The bending deformation if it were exactly in phase with the pitching motion would simply amount to a small change in the local position of the pitching axis. A few theoretical calculations made at the time of the experiments to examine the effect of changes of axis position on the unsteady aerodynamics showed that the measured amount of superimposed bending motion for 40 Hz is not likely to produce significant contributions to the oscillatory pressures.

With regard to the effects of the twisting deformation of the model, it can be inferred from Table 7.6 that the actual pitching motion at the sections $\eta = 0.524$ and 0.712 , where the unsteady pressures were measured, has (1) an amplitude rather larger than the reference θ_0 and (2) a small phase lead. The phase lead is never larger than 4° and its effect is probably negligible within the general accuracy of the measurements. Since no corrections for the model deformations have been applied to the tabulated data, which are normalised using the reference θ_0 , the increase in pitching amplitude at the unsteady measuring sections suggests that a user of the 40 Hz data would be justified in reducing the values of the normalised quantities R and I by a few percent.

No numerical data for 60 Hz are presented here but could be made available if required. For this frequency the bending motion of the wing is larger than for 40 Hz, and without an analysis it is not possible to conclude that its effect is insignificant. In the absence of such analysis, the 60 Hz data should be regarded as only qualitatively relating to the design mode of motion.

Steady flow

The steady flow at the upper surface can be inferred from the distributions of M_L shown in Figs 7.3 to 7.6.

When the incidence is near to zero, for all M , there is a small region of high suction and a recompression situated close to the leading edge. With increase of incidence, for each subsonic M the high suction region extends backwards over the chord and is terminated by a steep pressure gradient - the forward recompression. For higher subsonic M this is followed by another expansion region, which for $M = 0.95$ is terminated by a shock wave - the rear shock, aft of mid-chord. The three-dimensional nature of the flow when the model is at incidence can be seen in the isomachs of Fig 7.7.

Whereas there is no doubt about the existence of the rear shock, the exact nature of the flow over the more forward part of the chord is not absolutely clear. Although for some of the test conditions the local Mach numbers in this forward region are supersonic, it is not obvious that the forward recompression involves a shock wave. Certainly there is no possibility of a shock wave for $M = 0.80$ even at the highest incidence. It is therefore important to note that the general shape of the forward recompression remains essentially the same as M is increased up to its highest subsonic value $M = 0.95$. Furthermore, the high angle of sweepback of the isomachs in the forward recompression region, as seen in Fig 7.7, suggests that a shock wave will not be present. Instead it is probable that for much of the incidence range and for all subsonic Mach numbers, a leading-edge separation vortex extends across the upper surface.

Influence of incidence on the oscillatory pressures

An example of the influence of mean incidence on the oscillatory pressures for $M = 0.90$ is shown in Fig 7.8 which gives results for the upper surface (E) at sections 2 and 4 and for the lower surface (I) at section 2. It is the upper surface that is most affected by increasing positive incidence, the lower surface tending to retain the pattern it has for the non-lifting condition. Also, whereas for a non-lifting condition the distributions for the two spanwise positions are basically similar, with increase of incidence the characteristics for the upper surface become more three-dimensional and the leading-edge peaks in $R(X)$ and $I(X)$ move to the rear and broaden. These changes are doubtless related to the rearward displacement with incidence of the steady-flow recompression region, as already seen in Fig 7.4. For $\alpha_m = 30^\circ$, $R(X)$ and $I(X)$ at section 2E each consists of a leading-edge peak followed by several subsidiary peaks or 'crinkles', lying ahead of the rear shock peak which is situated at about 55% chord. With further increase of incidence to $\alpha_m = 50^\circ$, the crinkles have almost disappeared and have been replaced by a more regular distribution of forward and rear peaks. It would seem that this evolution is associated with successive stages in the development locally of high subsonic and eventually supersonic flow.

At section 4E with increase of incidence, $R(X)$ becomes negative over nearly all of the rearward half of the chord. At the highest incidence, $\alpha_m = 50^\circ$, the forward peak extends over much of the fore-chord as a result of the fanning-out of the forward recompression, possibly associated with the separated vortex flow suggested previously.

Influence of oscillation frequency

The effects of changing oscillation frequency are shown, at least qualitatively, for each of the CT combinations of M and α_m in Figs 7.9 to 7.15. For the non-lifting cases, Figs 7.9 to 7.12, results are shown for section 2E only; for the lifting cases, Figs 7.13 to 7.15, results are shown for both sections 2E and 4E.

Changing frequency is generally expected to affect the imaginary component and phase angle. For the non-lifting cases the frequency effects on the real component are not large when the flow is either completely subsonic (Fig 7.9 for $M = 0.8$) or completely supersonic (Fig 7.12 for $M = 1.10$). Greater sensitivity to frequency appears in both real and imaginary components where the local flow is close to sonic (Fig 7.10 for $M = 0.9$, near mid chord) or in the vicinity of the rear shock wave (Fig 7.12 for $M = 0.95$).

For the lifting cases (Figs 7.13 to 7.15) the real and imaginary components show considerable changes, not only at the rear shock wave, but also at the forward peaks.

Sensitivity to small changes in M and α_m

When comparisons between experimental and computational results are being made, it is helpful to be aware of the sensitivity to small variations in the parameters and of the uncertainties in the measurements. For the present model with sonic or near-sonic flow the real and imaginary distributions $R(X)$ and $I(X)$ are sensitive not only to frequency but also to small changes of M and α_m .

As shown in Fig 7.2 the tests for the mean conditions $M = 0.90$, $\alpha_m = 4^\circ$ and $M = 0.95$, $\alpha_m = 4.75^\circ$ corresponding to CT Cases 5 and 7 or 8 are each surrounded by eight neighbouring test cases with small differences in M and α_m . It is from these matrices of tests that information on sensitivity can be obtained.

Fig 7.16 shows for the initial condition $M = 0.90$, $\alpha_m = 4^\circ$, the separate effects of making changes of $\pm 0.2^\circ$ in α_m and ± 0.01 in M . Whilst the forward peaks in $R(X)$ and $I(X)$ show some sensitivity to the incidence change, it is the rear peaks that show most sensitivity to the Mach number change. The increase from $M = 0.89$ to $M = 0.90$ changes the mid-chord crinkles to a distribution with well-defined peaks. A further increase to $M = 0.91$ displaces the peaks to the rear.

For the initial condition $M = 0.95$, $\alpha_m = 4.75^\circ$ the distributions are relatively insensitive to incidence changes of 0.25° , but quite sensitive to the Mach number changes of ± 0.01 as shown in Fig 7.17. The distributions for section 2E demonstrate an important point: when a peak has become very sharp, it may just be detectable from only a single point, as for $M = 0.95$, or may even be 'lost' between measuring positions as we believe has happened for $M = 0.96$. Section 4E shows a highly sensitive negative peak in $R(X)$.

Figs 7.18 and 7.19 may be of special interest when assessing the significance of any differences between computational and experimental data. They show the measurements corresponding to the 40 Hz CT Cases for $M = 0.90$, $\alpha_m = 4^\circ$ and $M = 0.95$, $\alpha_m = 4.75^\circ$ within envelopes that enclose all the data measured for the surrounding test matrices. It is suggested the envelopes could be a help in deciding on the tolerances to be accepted when judging the results of computations.

For CT Cases 1, 4 and 6, as seen in Table 7.2, numerical data obtained in the ONERA S2 tunnel are included for comparison with the data obtained from the main source, the HST of NLR. For the conditions $M = 0.90$, $\alpha_m = 4^\circ$ and $M = 0.95$, $\alpha_m = 4.75^\circ$ corresponding to CT Cases 5 and 7 no measurements are available from the S2 tunnel. However comparisons between the two tunnels are available for the two nearby conditions, $M = 0.90$, $\alpha_m = 5^\circ$ and $M = 0.95$, $\alpha_m = 5^\circ$ and are shown in Figs 7.20 and 7.21. It must be emphasised that the results from both tunnels were obtained using the same techniques and with the same instrumentation, so that from these comparisons it is impossible to draw conclusions about any uncertainties arising from the instrumentation itself. The comparisons do however give some idea of the likely spread in the data from items such as tunnel interference, the character of the tunnel flow and the consistency of the parameter settings.

Since the results from the two tunnels are regarded as having equal 'weight', a theoretical result which, when compared with the results from one tunnel, shows similar discrepancies to those in Figs 7.20 and 7.21 could be regarded as being in general agreement with experiment.

1 GENERAL DESCRIPTION OF MODEL

1.1 Designation	NORA model
1.2 Type	Half model
1.3 Derivation	Horizontal tail surface of Mirage F1
1.4 Additional remarks	-
1.5 References	Ref 7.1

2 MODEL GEOMETRY

2.1 Planform	For the actual model, see Fig 7.1. For the computational model, see Ref 7.2 for modified planform with streamwise tip
2.2 Aspect ratio	2.01
2.3 Leading-edge sweep	50°
2.4 Trailing-edge sweep	13° 26'
2.5 Taper ratio	0.3515 (for the computational model)
2.6 Twist	None
2.7 Root chord	650 mm
2.8 Span of model	442.5 mm
2.9 Area of planform	0.1944 m ² (for the computational model)
2.10 Location of reference sections and definition of profiles	The profile is based on the symmetric NACA 63006 modified to a thickness ratio of about 5% and with a small updroop near the nose. For details of actual model, see Figs 45 and 46 of Ref 7.1. For the computational model, see Ref 7.2
2.11 Lofting procedure between reference sections	
2.12 Form of wing-body, or wing-root junction	Clearance between root and tunnel wall. Small fillet attached to model to cover shaft aperture, see Fig 4a of Ref 7.1
2.13 Form of wing tip	Actual model: sharp Computational model: square cut
2.14 Control surface details	None
2.15 Additional remarks	-
2.16 References	Refs 7.1, 7.2

3 WIND TUNNELS

3.1 Designation	HST: NLR High Speed Tunnel (HST) S2: ONERA Modane S2
3.2 Type of tunnel	HST: Continuous, variable pressure S2: Continuous, variable pressure
3.3 Test section dimensions	HST: Height = 1.60 m, width = 2.00 m, length = 2.50 m S2: Height = 1.77 m, width = 1.75 m, length = 5.40 m (of perforated part)
3.4 Type of roof and floor	HST: Slotted, each having four whole slots and a ½-slot at each corner S2: Perforated plates, with holes inclined 60° to the normal. Each plate is backed by a perforated sheet which can be slid to vary porosity
3.5 Type of side walls	HST: Solid S2: Solid
3.6 Ventilation geometry	HST: Roof and floor are 12% open S2: Porosity of roof and floor chosen according to Mach number. 1% open for M = 0.80 and M = 1.10; 6% open for M = 0.9 and M = 0.95
3.7 Thickness of side wall boundary layer	HST: 7 mm approximately S2: 90 to 170 mm
3.8 Thickness of boundary layers at roof and floor	HST: - S2: -
3.9 Method of measuring Mach number	HST: Derived from settling chamber stagnation and plenum chamber static pressures S2: -
3.10 Flow angularity	HST: - S2: -

3.11	Uniformity of Mach number over test section	HST: - S2: $\Delta M/\Delta x = \pm 3 \times 10^{-3} \text{ m}^{-1}$ for $0.70 < M < 0.92$
3.12	Sources and levels of noise or turbulence in empty tunnel	HST: Less than 1% in rms p/q for $M = 0.8$ S2: Velocity turbulence: 0.2%
3.13	Tunnel resonances	HST: } No evidence of resonance in present tests S2: }
3.14	Additional remarks	HST: Information about flow angularity and Mach number uniformity available only along test section centre-line S2: Accuracy of Mach number, $\Delta M = \pm 0.001$
3.15	References on tunnel	HST: Ref 7.3 S2: Refs 7.4, 7.5, 7.6

4 MODEL MOTION

4.1	General description	Rigid-body oscillation about swept axis shown in Fig 7.1. Sinusoidal in time
4.2	Reference coordinate and definition of motion	Rotation $\theta = \theta_0 \sin \omega t$ measured in streamwise plane $y = 0$ at the root
4.3	Range of amplitude	$0.25^\circ \leq \theta_0 \leq 1.00^\circ$
4.4	Range of frequency	Standard frequencies for main data: 5, 40 and 60 Hz. A few special tests at other frequencies up to 95 Hz, see Ref 7.1
4.5	Method of applying motion	Forced by hydraulic rotary actuator
4.6	Timewise purity of motion	Purity of sinusoid considered to be adequate
4.7	Natural frequencies and normal modes of model and support system	Lowest natural frequency of system: torsion of drive shaft at 100 Hz approximately
4.8	Actual mode of applied motion including any elastic deformation	See Introduction and Tables 7.5 and 7.6
4.9	Additional remarks	-

5 TEST CONDITIONS

5.1	Model planform area/tunnel area	HST: 0.06 S2: 0.06
5.2	Model span/tunnel width	HST: 0.22 S2: 0.25
5.3	Blockage	HST: } 0.3% for zero incidence S2: }
5.4	Position of model in tunnel	HST: Standard side-wall position S2: Standard wall mounting position
5.5	Range of Mach number	HST: $0.60 \leq M \leq 1.10$, see Table 7.1 S2: $0.80 \leq M \leq 0.95$
5.6	Range of tunnel total pressure	$0.46 \leq p_t \leq 0.9 \text{ bar}$, see Table 7.1
5.7	Range of tunnel total temperature	HST: $30^\circ\text{C} \leq T_0 \leq 38^\circ\text{C}$ S2: $18^\circ\text{C} \leq T_0 \leq 20^\circ\text{C}$
5.8	Range of model steady, or mean, incidence	HST: $0.5^\circ \leq \alpha_m \leq 5.0^\circ$ S2: $-1.0^\circ \leq \alpha_m \leq 5.0^\circ$
5.9	Definition of model incidence	Chord line of basic symmetrical section was datum for incidence
5.10	Position of transition, if free	-

5.11	Position and type of trip, if transition fixed	Metal tapes with 'coronets' about 0.09 mm high fixed at 5% local chord on both surfaces
5.12	Flow instabilities during tests	None encountered
5.13	Changes to mean shape of model due to steady aerodynamic load	Not measured, but considered negligible
5.14	Additional remarks	-
5.15	References describing tests	Ref 7.1

6 MEASUREMENTS AND OBSERVATIONS

- 6.1 Steady pressures for the mean conditions
- 6.2 Steady pressures for small changes from the mean conditions
- 6.3 Quasi-steady pressures
- 6.4 Unsteady pressures
- 6.5 Steady section forces for the mean conditions by integration of pressures
- 6.6 Steady section forces for small changes from the mean conditions by integration
- 6.7 Quasi-steady section forces by integration
- 6.8 Unsteady section forces by integration
- 6.9 Measurement of actual motion at points on model
- 6.10 Observation or measurement of boundary layer properties
- 6.11 Visualization of surface flow
- 6.12 Visualization of shock wave movements
- 6.13 Additional remarks

✓
-
✓
(5Hz)
✓
✓
✓
-
✓
(5Hz)
✓
✓
-
-
-
-
-
-

7 INSTRUMENTATION

- 7.1 Steady pressure
 - 7.1.1 Position of orifices spanwise and chordwise
 - 7.1.2 Type of measuring system
 - 7.2 Unsteady pressures
 - 7.2.1 Position of orifices spanwise and chordwise
 - 7.2.2 Diameter of orifices
 - 7.2.3 Type of measuring system
 - 7.2.4 Type of transducers
 - 7.2.5 Principle and accuracy of calibration
 - 7.3 Model motion
 - 7.3.1 Method of measuring motion reference coordinate
 - 7.3.2 Method of determining spatial mode of motion
 - 7.3.3 Accuracy of measured motions
- See Fig 7.1 and Table 7.3
Orifices connected by tubes to conventional tunnel-based system
- See Fig 7.1 and Table 7.3
0.8 mm
Each orifice closely connected to its own transducer installed within model
Kulite XCQL 093
Daily calibration using portable oscillatory pressure generator. Accuracy probably a few percent
- Rotary potentiometer attached to drive shaft, calibrated to give deflection θ
Six accelerometers installed within model; see Fig 7.1 and Table 7.4
Resolution of θ , about 0.01° . Accelerometers readings, accurate to a few percent

7.4 Processing of unsteady measurements

7.4.1 Method of acquiring and processing measurements

Pressure and accelerometer signals processed sequentially in groups by ten parallel channels. Each channel consisted of analogue circuitry giving output voltages proportional to Fourier fundamental components. Output voltages digitized and fed to computer for conversion to coefficients, display and disc-storage

7.4.2 Type of analysis

Components in phase and in quadrature with θ , averaged over 8 seconds

7.4.3 Unsteady pressure quantities obtained and accuracies achieved

Fundamental harmonic coefficients of pressure, accurate to a few percent. Chordwise integration to give section lift and moment contributions from upper and lower surfaces, but accuracy low because of wide spacing

7.4.4 Method of integration to obtain forces

Polygonal summation, see Appendix C of Ref 7.1

7.5 Additional remarks

-

7.6 References on techniques

-

8 DATA PRESENTATION

8.1 Test cases for which data could be made available

Table 7.1

8.2 Test cases for which data are included in this document

Table 7.2

8.3 Steady pressures

Tables 7.7 to 7.13

8.4 Quasi-steady or steady perturbation pressures

Data for 5 Hz in Tables 7.14 to 7.27

8.5 Unsteady pressures

Tables 7.14 to 7.30

8.6 Steady forces or moments

Not included

8.7 Quasi-steady or steady perturbation forces

Not included

8.8 Unsteady forces and moments

Not included

8.9 Other forms in which data could be made available

Unsteady pressures measured at tunnel roof

8.10 References giving other presentations of data

Ref 7.1

9 COMMENTS ON DATA

9.1 Accuracy

± 0.005

9.1.1 Mach number

$\pm 0.01^\circ$

9.1.2 Steady incidence

Better than $\pm 2\%$ of nominal values due to temperature variations

9.1.3 Reduced frequency

M_L to ± 0.005

9.1.4 Steady pressure coefficients

-

9.1.5 Steady pressure derivatives

The uncertainties in the coefficients R and I are probably $\pm 0.02 \pm 0.05\%$, where $R = |R|$ or $|I|$

9.1.6 Unsteady pressure coefficients

See Introduction and Figs 7.18 to 7.19

9.2 Sensitivity to small changes of parameter

Normalised pressure coefficients not sensitive to oscillation amplitude except for positions near the leading edge or a shock wave

9.3 Non-linearities

Effects of Reynolds number not examined

9.4 Influence of tunnel total pressure

- 9.5 Effects on data of uncertainty, or variation, in mode of model motion Not large for 5 Hz and 40 Hz. See Introduction and Tables 7.5 and 7.6
- 9.6 Wall interference corrections No corrections applied to any data. Values of M and a_m are tunnel settings
- 9.7 Other relevant tests on same model -
- 9.8 Relevant tests on other models of nominally the same shape -
- 9.9 Any remarks relevant to comparison between experiment and theory -
- 9.10 Additional remarks -
- 9.11 References on discussion of data Ref 7.1

10 PERSONAL CONTACT FOR FURTHER INFORMATION

Mr B.L. Welsh, Royal Aircraft Establishment, Bedford MK41 6AE, England (or, if convenient, any of the authors of Ref 7.1).

11 LIST OF REFERENCES

- 7.1 N. Lambourne R. Destuynder K. Kienappel R. Roos Comparative measurements in four European wind tunnels of the unsteady pressures on an oscillating model (the NORA experiments). (1980) Issued in each of the following forms:
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NLR TR 80066 U
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- 7.2 S.R. Bland AGARD three-dimensional aeroelastic configurations.
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- 7.3 - Users guide to the high speed wind tunnel.
HST of NLR (revised edition) (1977)
- 7.4 N. Pierre G. Fasso The aerodynamic test center of Modane Avrieux.
ONERA Technical Note 166B (1972)
- 7.5 N. Pierre G. Fasso Exploitation du centre d'essai aerothermodynamique de Modane Avrieux.
ONERA Note Technique 181 (1971)
- 7.6 V. Schmitt F. Charpin Experimental data base for computer program assessment.
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12 NOTATION

General

- c local chord
- c_r root chord
- $C_p^{\prime}/q_0, C_p^{\prime\prime}/q_0$ normalised fundamental in-phase and in-quadrature components of oscillatory pressure, respectively p'/q_0 and p''/q_0 (rad^{-1})
- E as in 2E, 4E, denotes extrados, or upper surface
- f oscillation frequency (Hz), $\omega/2\pi$
- I as in 2I, 4I, denotes intrados, or lower surface
- i normalized fundamental in-quadrature component of pressure, $-p''/p_t q_0$ (rad^{-1})
- $I(X)$ chordwise distribution of I
- k reduced frequency, $\omega c_r/2V$
- N stream Mach number

M_L	local Mach number at surface of model, $M_L = \left\{ 5 \left[\left(p/p_t \right)^{-2/7} - 1 \right] \right\}^{-1/2}$
p	pressure
p_t	stream total pressure
p^*, p''	fundamental components of pressure respectively in phase and in quadrature with oscillatory motion θ
q	stream dynamic pressure
R	normalised fundamental in-phase component of pressure $-p^*/p_{t0} \theta_0$ (rad ⁻¹)
$R(X)$	chordwise distribution of R
s	span of model
t	time
T_0	stream total temperature
v	stream velocity
x, y	coordinates in plane of model, see Fig 7.1
$x_{LE}(y)$	coordinate of local leading edge
$x_\alpha(y)$	local chordwise position of oscillation axis
X	local chordwise position, ξ
Z	upward displacement normal to plane of model
α	incidence of model (deg)
α_m	steady, or mean, incidence (deg)
η	non-dimensional spanwise position, y/s
θ	coordinate for specifying angular oscillatory motion, positive nose up, measured in planes parallel to plane $y = 0$. Reference at drive shaft $\theta = \theta_0 \sin \omega t$ (deg)
θ_0	reference amplitude of motion, identical to α_0 of Ref 7.2 (deg)
ξ	non-dimensional chordwise position, $(x - x_{LE})/c$
ω	oscillation frequency (rad ⁻¹)

Chordwise sections are identified 0E ... 6E and 0I ... 6I ; see Table 7.3 for positions.

Tables 7.7 to 7.13

MLOC	local Mach number, M_L
EXTR	extrados = upper surface
INTR	intrados = lower surface

Tables 7.14 to 7.30

PRESSURE stream total pressure, p_t

The factor $(C_p'/R) \equiv (C_p''/I)$, whose value F is given at the head of each table can be used to obtain C_p'/θ_0 and C_p''/θ_0 , but note that a change of sign is required, thus:

$$C_p'/\theta_0 = - R \times F$$

$$C_p''/\theta_0 = - I \times F .$$

Figures 7.8 to 7.12

$$\text{Modulus} = (R^2 + I^2)^{\frac{1}{2}}$$

$$\tan \phi = I/R .$$

Table 7.1
TEST NUMBERS OF DATA THAT CAN BE MADE AVAILABLE

Test numbers are necessarily different for different frequencies, but for the steady pressures they are often the same as those for one of the frequencies, usually 40 Hz. Data are included in this document for those numbers underlined

M	α_m (deg)	P _t (bars)	Steady	5 Hz	40 Hz	60 Hz	M	α_m (deg)	P _t (bars)	Steady	5 Hz	40 Hz	60 Hz
0.60	0.4	0.9	2006	2152	2006	2182	0.95	0	0.6	2046	2114	2046	2149
0.79	0.4	0.9	2007	2193	2007	2183	0.5	0.6	2028	2135	2028	2152	
0.79	0.4	0.9	2008	2126	2005	2175	1.0	0.6	2047	2115	2047	2150	
0.80	0	0.9	2010	2191	2009	2181	2.0	0.6	2048	2116	2048	2151	
0.80	0	0.9	2010	2185/2194	2010	2174/2184	2.0	0.46	2079	2096	2079	2212	
0.89	1.0	0.9	2011	2187	2011	2176	3.0	0.6	2051	2117	2118	-	
0.89	3.5	0.6	2019	2142	2019	2169	5.0	0.46	2084	2101	2084	2220	
0.89	3.8	0.6	2044	2161	2017/2044	2168	0.96	4.5	0.46	2088	2105	2088	2221
0.93	0.5	0.6	2041	2143	2042	2170	4.0	0.46	2081	2098	2081	2214	
0.93	0.5	0.6	2043	2144	2043	2173	4.5	0.46	2082	2099	2082	2218	
0.93	0.5	0.6	2024	2122	2024	2180	4.75	0.46	2083	2100	2083	2219	
0.51	3.5	0.6	2033	2139	2023	2166	1.10	0.6	2045	2113	2045	2148	
0.92	4.75	0.46	2201	2125	2029	2158							
0.93	5.0	0.46	2030	2126	2030	2160							
0.94	0	0.6	2031	2127	2031	2161							
0.94	4.5	0.6	2032	2128	2032	2162							
0.94	4.75	0.46	2034	2136	2034	2163							
0.95	4.2	0.6	2035	2138	2035	2164							
0.95	4.5	0.46	2206	2197	2206	2203							
0.95	5.0	0.46	2201	2199	2201	2204/2224							
0.96	4.0	0.6	2037	2119	2037	2154							
0.96	4.2	0.6	2040	2121	2038	2155							
0.97	4.75	0.46	2092	2109	2092	2205							
0.98	5.0	0.46	2093	2110	2093	2206							
0.98	0	0.6	2027	2134	2027	2153							
0.98	4.5	0.46	2035	2182	2085	2207							
0.98	4.75	0.46	2086	2103	2086	2208							
0.98	5.0	0.46	2087	2104	2087	2211							

Each set of measurements comprises:

Steady local Mach numbers, as in Tables 7.7 to 7.13

Oscillatory pressures, as in Tables 7.14 to 7.30

Accelerometer displacements, as in Table 7.5

Frequency parameter: k (nominal) = $5.8f(0.2 + M^{-2})^{0.5} \times 10^{-3}$

Reynolds number: the nominal value of $Re \times 10^{-6}$ for any Mach number can be interpolated from the following table:

M	P _t (bar)
0.60	0.46
0.80	-
0.80	0.80
0.90	0.90
0.90	4.2
0.95	3.95
1.00	4.4
1.10	5.7
1.10	-
	5.8

Table 7.2
DETAILS OF EXPERIMENTAL CASES FOR WHICH DATA ARE INCLUDED

CT Case	M	α_m (deg)	$\alpha_0 \equiv \theta_0$ (deg) nominal	f (Hz)	k nominal	P_t (bar)	$Re \times 10^{-6}$	Steady M_L		Oscillatory pressures			
								HST		HST		S2	
								Test No.	Table	Test No.	Table	Test No.	Table
-	0.80	0	0.5	5	0.038	0.90	7.8	2010	7.7	2185	7.14	-	-
1	0.80	0	0.5	40	0.31	0.90	7.8	2010	7.7	2010	7.15	80	7.28
-	0.80	4.0	0.5	5	0.038	0.90	7.8	2014	7.8	2190	7.16	-	-
2*	0.80	4.0	0.5	40	0.31	0.90	7.8	2014	7.8	2014	7.17	-	-
3	0.90	0	0.5	5	0.035	0.60	5.5	2029	7.9	2124	7.18	-	-
4	0.90	0	0.5	40	0.28	0.60	5.5	2029	7.9	2029	7.19	76	7.29
-	0.90	4.0	0.5	5	0.035	0.60	5.5	2035	7.10	2136	7.20	-	-
5*	0.90	4.0	0.5	40	0.28	0.60	5.5	2035	7.10	2035	7.21	-	-
-	0.95	0	0.5	5	0.034	0.60	5.6	2046	7.11	2114	7.22	-	-
6*	0.95	0	0.5	40	0.27	0.60	5.6	2046	7.11	2046	7.23	69	7.30
7	0.95	4.75	0.5	5	0.034	0.46	4.3	2083	7.12	2100	7.24	-	-
8	0.95	4.75	0.5	40	0.27	0.46	4.3	2083	7.12	2083	7.25	-	-
-	1.10	0.55	0.5	5	0.030	0.60	5.8	2045	7.13	2113	7.26	-	-
9	1.10	0.55	0.5	40	0.24	0.60	5.8	2045	7.13	2045	7.27	-	-

* Denotes CT priority case.

Table 7.3
POSITIONS OF PRESSURE HOLES

Section	0	1	2	3	4	5	6
y/s	0.133	0.389	0.524	0.612	0.712	0.786	0.895
Pressures	Steady	Steady	Unsteady	Steady	Unsteady	Steady	Steady
X =	0.0125 0.025 0.05 0.10 0.22 0.30 0.40 0.62 0.75 0.90	0.025 0.05 0.10 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.90	0.012 0.025 0.05 0.10 0.20 0.28 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.80 0.87	0.05 0.10 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.90	0.012 0.025 0.05 0.10 0.20 0.28 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.80 0.87	0.075 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.88	0.10 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.88
X =	0.0125 0.025 0.05 0.10 0.22 0.30 0.40 0.62 0.75 0.90 0.88	0.025 0.05 0.10 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.88	0.05 0.10 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.90 0.88	0.05 0.10 0.15 0.22 0.30 0.40 0.50 0.60 0.70 0.80 0.87	0.05 0.10 0.20 0.28 0.40 0.50 0.60 0.70 0.80 0.90 0.87	0.075 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.88	0.10 0.15 0.22 0.30 0.40 0.50 0.62 0.75 0.88

Table 7.4

POSITION OF ACCELEROMETERS IN RELATION TO x_a (y) THE CHORDWISE POSITION
OF THE DESIGN AXIS OF OSCILLATION

y/s	Forward position (A)		Rearward position (B)	
	Accel. No.	$x_a - x_A$ (mm)	Accel. No.	$x_B - x_a$ (mm)
0.169	1	260	2	180
0.655	3	110	4	90
0.931	5	55	6	48

Table 7.5

DISPLACEMENTS DEDUCED FROM ACCELEROMETERS. DISPLACEMENTS Z' AND Z'' , MEASURED IN mm,
ARE RESPECTIVELY IN-PHASE AND IN-QUADRATURE COMPONENTS PHASE REFERENCED
TO DATUM ANGULAR DISPLACEMENT θ

Note: These are taken from Ref 7.1 but a change of sign has been applied throughout

Test No.	$n = 0.169$				$n = 0.655$				$n = 0.931$			
	Accel. No.1 (A)		Accel. No.2 (B)		Accel. No.3 (A)		Accel. No.4 (B)		Accel. No.5 (A)		Accel. No.6 (B)	
	Z'_A	Z''_A	Z'_B	Z''_B	Z'_A	Z''_B	Z'_A	Z''_B	Z'_A	Z''_B	Z'_A	Z''_B
2010	2.322	0.086	-1.602	-0.038	1.148	0.072	-0.672	0.027	0.753	0.089	-0.211	0.084
2014	2.305	0.125	-1.570	-0.080	1.184	0.083	-0.598	-0.009	0.847	0.077	-	0.056
2029	2.314	0.104	-1.614	-0.058	1.116	0.073	-0.708	0.009	0.709	0.086	-0.271	0.056
2035	2.271	0.150	-1.567	-0.100	1.138	0.089	-0.639	-0.023	0.769	0.080	-0.153	0.053
2046	2.297	0.079	-1.590	-0.051	1.130	0.052	-0.661	0.009	0.743	0.061	-0.209	0.044
2083	2.282	0.113	-1.584	-0.092	1.124	0.040	-0.653	-0.047	0.756	0.019	-0.203	-0.033
2045	2.323	0.046	-1.590	-0.049	1.173	0.009	-0.621	-0.029	0.802	0.000	-0.143	-0.016

Table 7.6

LOCAL DISPLACEMENTS IN PITCH (θ, ϵ_0)_n AND NORMAL TRANSLATION OF DESIGN AXIS (Z, ϵ_z)_n
PHASE REFERENCED TO DATUM $\theta = \theta_0 \sin \omega t$. COMPLEX QUANTITIES θ_n AND Z_n ARE DERIVED
FROM TABLES 7.4 AND 7.5 ON THE BASIS THAT CHORDWISE SECTIONS DO NOT DEFORM, THUS

$$\theta_n = (Z_A - Z_B)/(x_B - x_A), \quad Z_n = [Z_A(x_B - x_A) + Z_B(x_A - x_B)]/(x_B - x_A)$$

CT Case	M	a_m	Test No.	θ_0	$n = 0.169$				$n = 0.655$				$n = 0.931$			
					θ (deg)	ϵ_0 (deg)	Z (mm)	ϵ_z (deg)	θ (deg)	ϵ_0 (deg)	Z (mm)	ϵ_z (deg)	θ (deg)	ϵ_0 (deg)	Z (mm)	ϵ_z (deg)
1	0.80	0	2010	0.50	0.51	2	0.01	76	0.52	1	0.15	18	0.54	0	0.25	20
2	0.80	4.0	2014	0.50	0.50	3	0.01	14	0.51	2	0.21	9	-	-	-	-
4	0.90	0	2029	0.50	0.51	2	0.01	-49	0.52	2	0.12	19	0.55	2	0.20	21
5	0.90	4.0	2035	0.50	0.50	4	0.00	-	0.51	4	0.16	10	0.51	2	0.28	13
6	0.95	0	2046	0.50	0.51	2	0.00	-	0.51	1	0.15	11	0.53	1	0.24	12
P	0.95	4.75	2083	0.48	0.50	3	0.01	-106	0.51	3	0.15	-3	0.54	3	0.24	-2
9	1.10	0.55	2045	0.50	0.51	1	0.01	-43	0.51	1	0.19	-4	0.53	1	0.30	-2

NORA TEST 2010 MACH=.802

Table 7.7

X	SECTION 0		SECTION 1		SECTION 3		SECTION 5		SECTION 6	
	MLOC	MLOC	EXTR	INTR	MLOC	MLOC	EXTR	INTR	MLOC	MLOC
.012	.883	.814	.834	.838	.802	.754	.816	.845	.818	.855
.025	.759	.817	.816	.861	.825	.852	.825	.854	.820	.848
.050	.763	.815	.816	.861	.829	.852	.839	.847	.840	.853
.075	.782	.826	.818	.844	.867	.850	.846	.854	.847	.866
.100	.808	.828	.814	.849	.841	.855	.859	.862	.857	.856
.150	.820	.843	.850	.855	.867	.870	.871	.862	.851	.854
.220	.827	.852	.867	.863	.862	.872	.860	.864	.831	.836
.300	.838	.850	.855	.850	.869	.870	.858	.864	.805	.813
.400	.840	.852	.862	.862	.871	.862	.860	.861		
.500	.841	.844	.861	.865	.860	.860	.841	.850		
.620	.795	.807	.827	.835	.822	.828	.816	.822		
.750	.804	.804	.781	.799	.774	.74	.772	.790		
.900										

NORA TEST 2014 MACH=.802

X	SECTION 0		SECTION 1		SECTION 3		SECTION 5		SECTION 6	
	MLOC	MLOC	EXTR	INTR	MLOC	MLOC	EXTR	INTR	MLOC	MLOC
.012	.4126	.697	.1.087	.707	.1.102	.730	.1.153	.735		
.025	.911	.726	.1.101	.726						
.050	.634	.737								
.075										
.100	.843	.768	.943	.767	.1.113	.761				
.150										
.220										
.300										
.400										
.500										
.620	.856	.821	.897	.833	.897	.827	.876	.838	.842	.846
.750	.802	.803	.883	.836	.874	.835	.852	.838	.829	.837
.900	.805	.805	.838	.820	.829	.818	.824	.820	.811	.818

Table 7.8

NODRA Test 2029 MACHE, 903

Table 7.9

Table 7.11

WABE TEST 2046 MARCH 1954

X	SECTION 0		SECTION 1		SECTION 3		SECTION 5		SECTION 6	
	MLUC	INTR	EXTR	INTR	MLUC	INTR	EXTR	INTR	MLUC	INTR
.012	.048	.945	1.071	.981						
.025	.952	.953	.966	1.017						
.050	.892	.960								
.075	.925	.975	.975	1.006						
.100			.968	1.013						
.125			.968	1.013						
.150			.976	1.012						
.175			.976	1.000						
.200			.976	1.027						
.225			.976	1.024						
.250			.988	1.024						
.275			.988	1.062						
.300			.988	1.061						
.325			.988	1.074						
.350			.988	1.074						
.375			.988	1.129						
.400			.988	1.129						
.425			.988	1.123						
.450			.988	1.123						
.475			.988	1.128						
.500			.988	1.128						
.525			.988	1.128						
.550			.988	1.128						
.575			.988	1.128						
.600			.988	1.128						
.625			.988	1.128						
.650			.988	1.128						
.675			.988	1.128						
.700			.988	1.128						
.725			.988	1.128						
.750			.988	1.128						
.775			.988	1.128						
.800			.988	1.128						

Table 7.12

MACH-E-451 MONGRA TEST 2083

SECTION 0		SECTION 1		SECTION 3		SECTION 5		SECTION 6	
X	MLUC	MLUC	MLUC	MLUC	MLUC	MLUC	MLUC	MLUC	MLUC
.0112	1.276	.794							
.0225	1.297	.832	1.285	.813					
.0500	1.005	.859	1.314	.856	1.362	.853	1.457	.862	
.0725	.987	.868	1.280	.894	1.403	.892			
.1150			1.113	.911	1.360	.912	1.355	.914	
.2220	1.023	.906	1.073	.917	1.203	.926	1.265	.927	
.3300	1.077	.938	1.105	.946	1.103	.955	1.232	.953	
.4000	1.074	.955	1.127	.971	1.158	.971	1.217	.989	
.5000			1.145	1.011	1.201	.998	1.200	1.041	
.6200	1.122	.996	1.188	1.022	1.212	1.033	1.041	1.069	
.7500	.962	.963	1.060	.999	.958	1.011	.975	.986	
.9000	.955	.955	.910	.950	.901	.938	.922	.931	

NORA TEST 2045 MACH=1.102

X	SECTION 0		SECTION 1		SECTION 3		SECTION 5		SECTION 6	
	MLOC	MLUC	EXTR	INTR	EXTR	INTR	EXTR	INTR	EXTR	INTR
.012	1.236	1.040								
.025	1.212	1.057	1.240	1.062						
.050	1.007	1.082	1.080	1.082						
.075										
.100	1.034	1.099	1.084	1.082	1.120	1.115	1.083	1.109		
.150			1.080	1.123	1.132	1.129				
.220	1.064	1.066	1.137	1.107	1.167	1.145	1.124	1.141		
.300	1.120	1.120	1.157	1.134	1.140	1.144	1.158	1.125		
.400	1.122	1.142	1.168	1.145	1.190	1.173	1.167	1.150		
.500			1.172	1.176	1.234	1.191	1.178	1.148		
.620	1.248	1.242	1.242	1.229	1.260	1.232	1.235	1.204		
.750	1.214	1.236	1.257	1.236	1.279	1.260	1.268	1.252		
.900	1.108	1.108	1.224	1.251	1.248	1.316	1.327	1.305		
							1.297	1.338		

Table 7.14

NORA TEST 2185 MACH=.855 FREQUENCY= 5-HZ PRESSURE=.9# BAR CP'/R=CP'/I=3.45

X	SECTION 2E		SECTION 2I		SECTION 4E		SECTION 4I	
	R	I	R	I	X	R	I	R
.012	2.792	.0.227						
.025	-5.782	-5.816						
.050	5.213	5.882						
.075	5.982	5.878						
.100	5.878	5.845						
.150	5.664	5.263	2.285	5.751	5.875	-5.826	-5.888	-5.849
.220	5.572	5.868	5.285	5.615	5.876	-5.749	-5.865	-5.883
.300	5.581	5.867	5.358	5.529	5.871	-5.647	-5.874	-5.867
.400	5.428	5.859	5.458	5.484	5.859	-5.539	-5.531	-5.473
.450	5.379	5.878	5.458	5.263	5.854	-5.454	-5.477	-5.469
.500	5.235	5.866	5.585	5.293	5.137	-5.388	-5.366	-5.316
.620	5.285	5.855	5.651	5.242	5.843	-5.343	-5.357	-5.362
.750	5.238	5.847	5.681	5.191	5.843	-5.243	-5.357	-5.342
.900	5.173	5.839	5.651	5.893	5.835	-5.136	-5.339	-5.181
			5.781	5.879	5.831	-5.816	-5.812	-5.835
					-5.871	-5.858		

Table 7.15

NORA TEST 2195 MACH=5.05 FREQUENCY= 45.1HZ PRESSURE=5.95 BAR CP'/R=CP'/I=2.45

SECTION 2E			SECTION 4E			SECTION 21			SECTION 41		
X	R	I	X	R	I	X	R	I	X	R	I
-5.25	3.378	-5.935	-5.616	5.281	-5.812	4.815	-5.196	-5.899	-5.557	-5.999	-5.254
-5.25	1.132	-5.187	5.815	-5.849	-5.056	5.819	-5.292	-5.978	-5.881	-5.953	-5.155
-5.25	6.632	-5.625	6.553	5.128	-5.267	5.732	-5.557	-5.568	-5.155	-5.785	-5.028
-5.25	5.553	5.128	5.478	5.156	-5.256	5.492	-5.125	-5.397	-5.617	-5.617	-5.635
-5.25	4.425	5.183	4.425	5.288	-5.428	5.397	-5.284	-5.353	-5.353	-5.515	-5.113
-5.25	3.353	5.246	3.331	5.246	-5.588	5.274	-5.284	-5.181	-5.379	-5.161	-5.161
-5.25	2.289	5.219	2.228	5.245	-5.551	5.247	-5.198	-5.194	-5.243	-5.243	-5.194
-5.25	1.162	5.211	1.162	5.211	-5.651	5.592	-5.178	-5.284	-5.284	-5.284	-5.178
-5.25	0.121	5.234	0.857	5.215	-5.781	5.864	-5.284	-5.881	-5.131	-5.197	-5.197
-5.25	0.887	5.184	0.887	5.184	-5.871	5.814	-5.144	-5.871	-5.128	-5.872	-5.162

Table 7.16

NORA TEST 2195 MACH=5.05 FREQUENCY= 5.HZ PRESSURE=5.95 BAR CP'/R=CP'/I=3.39

SECTION 2E			SECTION 4E			SECTION 21			SECTION 41		
X	R	I	X	R	I	X	R	I	X	R	I
-5.12	1.138	5.113	-5.125	5.125	-5.825	5.124	-5.124	-5.931	-5.758	-5.788	-5.849
-5.12	1.085	5.114	-5.025	5.115	-5.867	5.133	-5.144	-5.853	-5.767	-5.866	-5.849
-5.12	0.992	5.115	-5.055	5.135	-5.422	5.152	-5.152	-5.853	-5.598	-5.866	-5.839
-5.12	1.185	5.235	-5.055	5.075	-5.683	5.285	-5.169	-5.233	-5.199	-5.664	-5.664
-2.85	1.073	5.075	-2.85	5.048	-5.285	5.233	-5.153	-5.153	-5.538	-5.664	-5.538
-2.85	0.954	5.048	-2.85	5.055	-5.258	5.216	-5.116	-5.076	-5.439	-5.866	-5.856
-2.85	0.995	5.125	-2.85	5.251	-5.459	5.516	-5.439	-5.439	-5.398	-5.398	-5.398
-4.85	0.161	5.288	-4.85	5.866	-5.458	5.417	-5.869	-5.869	-5.361	-5.861	-5.357
-4.85	0.221	5.288	-4.85	5.868	-5.566	5.837	-5.868	-5.868	-5.868	-5.868	-5.853
-6.55	0.164	5.056	-6.55	5.125	-5.651	5.153	-5.848	-5.254	-5.245	-5.854	-5.854
-6.55	0.248	5.048	-6.55	5.276	-5.651	5.127	-5.832	-5.832	-5.287	-5.832	-5.228
-6.55	0.276	5.032	-6.55	5.368	-5.751	5.159	-5.892	-5.892	-5.185	-5.844	-5.844
-6.55	0.316	5.016	-6.55	5.816	-5.871	5.816	-5.816	-5.816	-5.781	-5.896	-5.832
-6.55	0.344	5.016	-6.55	5.816	-5.871	5.816	-5.816	-5.816	-5.816	-5.828	-5.828

Table 7.17

MORA TEST 2124 MACH=5.95 FREQUENCY= 45. HZ PRESSURE=5.95 BAR CP'/R=CP'/I=3.39

SECTION 2E		SECTION 4E			SECTION 2I			SECTION 4I		
X	R	X	R	I	X	R	I	X	R	I
.812	1.885	.812	1.921	1.274	.812	1.925	1.274	.849	-1.889	1.189
.825	1.845	.825	1.914	1.155	.825	1.896	1.155	.165	-8.881	8.835
.858	1.837	.858	1.986	1.055	.858	1.956	1.055	.199	-8.546	8.877
.188	2.555	.188	2.666	2.555	.188	2.668	2.555	.286	-8.525	8.182
.288	1.566	.288	2.756	1.566	.288	2.758	1.566	.285	-8.491	8.119
.285	8.156	.285	2.323	8.156	.285	2.325	8.156	.285	-8.491	8.119
.258	8.199	.258	1.394	8.199	.258	1.394	8.199	.258	-8.475	8.119
.485	8.248	.485	1.392	.485	.485	1.375	.485	.399	-8.451	8.163
.458	8.238	.458	2.84	.458	.458	2.817	.458	.399	-8.431	8.178
.688	8.252	.688	2.98	.688	.688	2.952	.688	.633	-8.326	8.179
.658	8.183	.658	2.916	.658	.658	2.884	.658	.601	-8.326	8.179
.658	8.135	.658	3.392	.658	.658	3.364	.658	.601	-8.287	8.179
.658	8.135	.658	1.35	.658	.658	1.338	.658	.601	-8.257	8.177
.658	8.135	.658	2.666	.658	.658	2.637	.658	.601	-8.192	8.177
.658	8.135	.658	2.54	.658	.658	2.51	.658	.751	-8.156	8.176
.758	8.167	.758	2.88	.758	.758	2.853	.758	.751	-8.178	8.176
.888	8.135	.888	2.88	.888	.888	2.853	.888	.871	-8.163	8.163
.878	8.118	.878	1.555	.878	.878	1.535	.878	.871	-8.163	8.163

Table 7.18
MORA TEST 2124 MACH=5.95 FREQUENCY= 5. HZ PRESSURE=5.67 BAR CP'/R=CP'/I=2.97

SECTION 2E		SECTION 4E			SECTION 2I			SECTION 4I		
X	R	X	R	I	X	R	I	X	R	I
.812	2.939	.812	2.883	5.383	.812	2.854	5.383	.849	-2.239	8.117
.825	3.888	.825	2.857	3.856	.825	2.827	3.856	.188	-1.471	8.897
.858	1.236	.858	1.871	1.871	.858	1.971	1.871	.188	-1.638	8.888
.188	1.852	.188	1.293	1.852	.188	1.293	1.852	.288	-8.771	8.876
.288	8.785	.288	1.852	2.88	.288	1.852	2.88	.288	-8.849	8.879
.288	8.785	.288	1.852	2.88	.288	1.852	2.88	.288	-8.849	8.879
.358	8.682	.358	1.852	3.58	.358	1.852	3.58	.399	-8.794	8.886
.488	8.658	.488	1.887	4.88	.488	1.887	4.88	.488	-8.653	8.891
.458	8.583	.458	1.852	4.58	.458	1.852	4.58	.581	-8.494	8.884
.688	8.523	.688	1.852	6.88	.688	1.852	6.88	.688	-8.558	8.881
.658	8.398	.658	1.852	6.58	.658	1.852	6.58	.658	-8.558	8.881
.658	8.258	.658	1.852	6.58	.658	1.852	6.58	.658	-8.562	8.881
.658	8.132	.658	1.852	6.58	.658	1.852	6.58	.658	-8.562	8.881
.758	8.854	.758	1.852	7.58	.758	1.852	7.58	.758	-8.533	8.881
.888	8.835	.888	1.852	8.88	.888	1.852	8.88	.871	-8.533	8.881
.878	8.818	.878	1.852	8.87	.878	1.852	8.87	.871	-8.565	8.881

Table 7.19

HORA TEST 2123 MACH=5.95 FREQUENCY= 45. HZ PRESSURE=5.65 BAR CP'/R=CP'/I=2.97

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
.812	3.458	-1.696	.812	4.882	-1.681				.849	-1.979	.569
.8125	2.756	-3.651	.8125	3.527	-8.953				.188	-1.394	.254
.815	1.122	-8.288	.815	1.924	-8.517				.199	-8.967	.955
.8165	8.957	-8.163	.8165	1.88	-8.242				.288	-8.829	.111
.8205	8.768	-8.637	.8205	2.85	-8.645						
.8235	8.744	-8.621	.8235	8.839	-8.654						
.8255	8.739	-8.695	.8255	8.853	-8.711						
.8285	8.734	-8.137	.8285	8.745	-8.386						
.8315	8.648	-8.219	.8315	8.519	-8.271						
.835	8.617	-8.337	.835	8.353	-8.333						
.8355	8.459	-8.333	.8355	8.215	-8.334						
.837	8.478	-8.359	.837	8.681	-8.357						
.8385	8.149	-8.332	.8385	8.651	-8.649						
.8395	8.653	-8.358	.8395	7.81	-8.622						
.843	-8.811	-8.247	.843	-8.851	-8.854						
.875	-8.811	-8.180	.875	-8.671	-8.644						

Table 7.20

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
.812	1.657	8.695	.812	2.487	8.166				.849	-1.281	.892
.8125	1.626	8.695	.8125	1.632	8.119				.188	-8.964	.883
.8155	1.215	8.695	.8155	1.156	8.689				.199	-8.714	.677
.8165	2.995	8.178	.8165	1.08	8.755				.288	-8.654	.865
.8205	4.792	8.155	.8205	3.499	8.149						
.8235	8.688	8.866	.8235	2.88	4.223						
.8255	8.382	8.853	.8255	2.656	8.268						
.8285	8.713	8.838	.8285	1.331	8.172						
.8315	8.374	8.864	.8315	4.88	8.839						
.835	8.183	8.213	.835	8.151	8.124						
.8385	8.138	8.869	.8385	8.189	8.842						
.843	8.836	8.853	.843	8.262	8.847						
.855	-8.875	-8.875	.855	8.612	8.838						
.795	8.842	8.842	.795	8.131	8.836						
.885	8.818	8.876	.885	-8.845	8.836						
.875	8.824	8.838	.875	8.871	8.824						

Table 7.21
MACH=8.95 FREQUENCY= 45.HZ PRESSURE=.65 BAR CP'/R=CP'/I=2.98

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
.812	1.285	-8.343	.812	2.358	-8.611	.812	2.358	-8.239	.812	8.958	-8.195
.825	1.382	-8.313	.825	1.651	-8.232	.825	1.651	-8.127	.825	8.847	-8.155
.838	1.195	-8.264	.838	8.828	-8.177	.838	8.828	-8.177	.838	8.821	-8.132
.851	2.416	-8.781	.851	2.757	-8.177	.851	2.757	-8.177	.851	8.747	-8.137
.864	2.294	-1.611	.864	2.229	-1.688	.864	2.229	-1.688	.864	8.692	-8.137
.878	8.685	-8.672	.878	2.725	-8.761	.878	2.725	-8.761	.878	8.687	-8.137
.891	8.685	-8.672	.891	4.858	2.178	.891	4.858	2.178	.891	8.687	-8.137
.904	8.761	-8.169	.904	4.858	1.958	.904	4.858	1.958	.904	8.687	-8.137
.917	8.685	-8.417	.917	5.385	8.748	.917	5.385	8.748	.917	8.687	-8.137
.930	1.385	-8.369	.930	5.226	8.586	.930	5.226	8.586	.930	8.687	-8.137
.943	1.122	-1.164	.943	8.651	-8.627	.943	8.651	-8.627	.943	8.687	-8.137
.956	-8.375	8.696	.956	8.631	-8.128	.956	8.631	-8.128	.956	8.687	-8.137
.969	-8.128	8.446	.969	8.321	8.253	.969	8.321	8.253	.969	8.687	-8.137
.982	-8.364	8.768	.982	8.318	8.218	.982	8.318	8.218	.982	8.687	-8.137
.995	8.511	8.247	.995	8.316	8.225	.995	8.316	8.225	.995	8.687	-8.137
.018	8.621	8.191	.018	8.386	8.149	.018	8.386	8.149	.018	8.687	-8.137

Table 7.22
MACH=8.95 FREQUENCY= 5.HZ PRESSURE=.65 BAR CP'/R=CP'/I=2.82

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
.812	3.878	8.281	.812	5.878	8.281	.812	5.878	8.281	.812	8.653	-8.195
.825	2.532	8.168	.825	4.969	8.285	.825	4.969	8.285	.825	8.653	-8.195
.838	1.185	8.562	.838	1.458	8.658	.838	1.458	8.658	.838	8.653	-8.195
.851	1.878	8.558	.851	2.864	8.658	.851	2.864	8.658	.851	8.653	-8.195
.864	8.446	8.558	.864	8.968	8.647	.864	8.968	8.647	.864	8.646	-8.195
.878	8.567	8.641	.878	2.868	8.826	.878	2.868	8.826	.878	8.646	-8.195
.891	8.564	8.641	.891	1.846	8.876	.891	1.846	8.876	.891	8.646	-8.195
.904	8.748	8.635	.904	8.754	8.853	.904	8.754	8.853	.904	8.653	-8.195
.917	8.657	8.621	.917	8.765	8.657	.917	8.765	8.657	.917	8.653	-8.195
.930	8.778	8.678	.930	8.441	8.265	.930	8.441	8.265	.930	8.653	-8.195
.943	8.717	8.647	.943	8.677	8.675	.943	8.677	8.675	.943	8.653	-8.195
.956	8.594	8.756	.956	8.735	8.254	.956	8.735	8.254	.956	8.653	-8.195
.969	8.794	8.284	.969	8.651	8.138	.969	8.651	8.138	.969	8.653	-8.195
.982	8.826	8.158	.982	8.464	8.886	.982	8.464	8.886	.982	8.653	-8.195
.995	8.225	8.856	.995	8.179	8.815	.995	8.179	8.815	.995	8.653	-8.195

Table 7.23
MORA TEST 2346 MACH=0.95 FREQUENCY= 48. HZ PRESSURE=0.65 BAR CP'/R=CP'/I=2.82

SECTION 21			SECTION 41		
X	R	I	X	R	I
.612	2.249	1.812	.612	4.848	-1.344
.625	2.437	1.762	.625	3.947	-1.164
.638	2.915	3.215	.638	2.267	-2.343
.651	3.168	3.179	.651	1.854	-5.284
.664	3.617	3.827	.664	1.744	-5.281
.678	3.467	3.664	.678	1.733	-5.284
.691	3.855	3.613	.691	1.748	-5.222
.704	3.574	3.859	.704	1.627	-5.527
.718	3.528	3.863	.718	1.635	-5.626
.731	3.672	3.873	.731	1.621	-5.625
.744	3.662	3.662	.744	1.734	-5.446
.758	3.621	3.662	.758	1.734	-5.153
.771	3.597	3.321	.771	2.658	-5.317
.784	3.287	3.719	.784	1.985	-5.828
.798	3.233	3.644	.798	1.837	-5.247
.811	3.198	3.318	.811	1.438	-5.224
.824			.824	0.127	

Table 7.24
MORA TEST 2188 MACH=0.95 FREQUENCY= 5. HZ PRESSURE=0.46 BAR CP'/R=CP'/I=2.83

SECTION 21			SECTION 41		
X	R	I	X	R	I
.612	1.697	1.667	.612	1.735	1.673
.625	1.623	1.867	.625	1.748	1.867
.638	1.515	1.868	.638	1.824	1.868
.651	2.224	1.113	.651	1.859	1.868
.664	1.167	1.141	.664	2.316	1.894
.678	2.416	1.182	.678	3.222	2.087
.691	1.389	1.867	.691	2.378	2.087
.704	1.101	1.867	.704	2.448	2.117
.718	1.252	1.866	.718	1.558	1.119
.731	1.262	1.853	.731	1.588	0.368
.744	1.516	1.847	.744	1.422	0.674
.758	1.545	1.848	.758	1.391	0.863
.771	1.972	1.867	.771	1.283	1.127
.784	1.958	1.856	.784	1.222	1.195
.798	1.843	1.843	.798	1.195	0.861
.811			.811	0.283	0.847

Table 7.25

NORA TEST 2883 MACH=8.95 FREQUENCY= 45. HZ PRESSURE=8.46 BAR CP'/R=CP'/I=2.83

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
-6.12	1.178	-8.385	-6.12	1.243	-8.556	-8.49	-1.126	8.171	-8.49	-1.126	8.171
-6.25	1.165	-8.374	-6.25	1.243	-8.518	-8.516	-1.652	8.158	-8.516	-1.652	8.158
-6.38	1.156	-8.368	-6.38	1.243	-8.479	-8.479	-1.652	8.158	-8.479	-1.652	8.158
-6.51	1.143	-8.365	-6.51	1.297	-8.479	-8.479	-1.652	8.158	-8.479	-1.652	8.158
-6.64	1.130	-8.362	-6.64	1.285	-8.449	-8.449	-1.652	8.158	-8.449	-1.652	8.158
-6.77	1.118	-8.362	-6.77	1.285	-8.423	-8.423	-1.652	8.158	-8.423	-1.652	8.158
-6.90	1.105	-8.362	-6.90	1.285	-8.397	-8.397	-1.652	8.158	-8.397	-1.652	8.158
-7.03	1.092	-8.362	-7.03	1.285	-8.371	-8.371	-1.652	8.158	-8.371	-1.652	8.158
-7.16	1.079	-8.362	-7.16	1.285	-8.345	-8.345	-1.652	8.158	-8.345	-1.652	8.158
-7.29	1.066	-8.362	-7.29	1.285	-8.319	-8.319	-1.652	8.158	-8.319	-1.652	8.158
-7.42	1.053	-8.362	-7.42	1.285	-8.293	-8.293	-1.652	8.158	-8.293	-1.652	8.158
-7.55	1.040	-8.362	-7.55	1.285	-8.267	-8.267	-1.652	8.158	-8.267	-1.652	8.158
-7.68	1.027	-8.362	-7.68	1.285	-8.241	-8.241	-1.652	8.158	-8.241	-1.652	8.158
-7.81	1.014	-8.362	-7.81	1.285	-8.215	-8.215	-1.652	8.158	-8.215	-1.652	8.158
-7.94	1.001	-8.362	-7.94	1.285	-8.189	-8.189	-1.652	8.158	-8.189	-1.652	8.158
-8.07	9.888	-8.362	-8.07	1.285	-8.163	-8.163	-1.652	8.158	-8.163	-1.652	8.158
-8.20	9.775	-8.362	-8.20	1.285	-8.137	-8.137	-1.652	8.158	-8.137	-1.652	8.158
-8.33	9.662	-8.362	-8.33	1.285	-8.111	-8.111	-1.652	8.158	-8.111	-1.652	8.158
-8.46	9.549	-8.362	-8.46	1.285	-8.085	-8.085	-1.652	8.158	-8.085	-1.652	8.158
-8.59	9.436	-8.362	-8.59	1.285	-8.059	-8.059	-1.652	8.158	-8.059	-1.652	8.158
-8.72	9.323	-8.362	-8.72	1.285	-8.033	-8.033	-1.652	8.158	-8.033	-1.652	8.158
-8.85	9.210	-8.362	-8.85	1.285	-8.007	-8.007	-1.652	8.158	-8.007	-1.652	8.158
-8.98	9.097	-8.362	-8.98	1.285	-8.081	-8.081	-1.652	8.158	-8.081	-1.652	8.158
-9.11	8.984	-8.362	-9.11	1.285	-8.055	-8.055	-1.652	8.158	-8.055	-1.652	8.158
-9.24	8.871	-8.362	-9.24	1.285	-8.029	-8.029	-1.652	8.158	-8.029	-1.652	8.158
-9.37	8.758	-8.362	-9.37	1.285	-8.003	-8.003	-1.652	8.158	-8.003	-1.652	8.158
-9.50	8.645	-8.362	-9.50	1.285	-8.077	-8.077	-1.652	8.158	-8.077	-1.652	8.158
-9.63	8.532	-8.362	-9.63	1.285	-8.051	-8.051	-1.652	8.158	-8.051	-1.652	8.158
-9.76	8.419	-8.362	-9.76	1.285	-8.025	-8.025	-1.652	8.158	-8.025	-1.652	8.158

NORA TEST 2113 MACH=1.18 FREQUENCY= 5. HZ PRESSURE=8.68 BAR CP'/R=CP'/I=2.52

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
-6.12	2.475	8.198	-6.12	2.643	8.194	-8.49	-1.451	8.071	-8.49	-1.713	8.065
-6.25	2.389	8.189	-6.25	2.453	8.186	-8.26	-1.874	8.053	-8.26	-1.671	8.058
-6.38	2.342	8.124	-6.38	2.353	8.126	-8.047	-2.86	8.017	-8.047	-1.99	8.033
-6.51	2.792	8.053	-6.51	1.126	8.074	-8.035	-2.86	8.013	-8.035	-2.86	8.019
-6.64	2.935	8.022	-6.64	2.285	8.098	-8.048	-2.86	8.013	-8.048	-2.86	8.019
-6.77	3.022	8.012	-6.77	3.353	8.052	-8.052	-2.86	8.013	-8.052	-2.86	8.019
-6.90	3.031	8.013	-6.90	3.423	8.082	-8.056	-2.86	8.013	-8.056	-2.86	8.019
-7.03	3.047	8.017	-7.03	4.452	8.090	-8.035	-2.86	8.013	-8.035	-2.86	8.019
-7.16	3.065	8.017	-7.16	5.076	8.133	-8.229	-2.86	8.013	-8.229	-2.86	8.019
-7.29	3.083	8.017	-7.29	5.551	8.152	-8.25	-2.86	8.013	-8.25	-2.86	8.019
-7.42	3.101	8.017	-7.42	6.691	8.161	-8.261	-2.86	8.013	-8.261	-2.86	8.019
-7.55	3.119	8.017	-7.55	7.353	8.175	-8.272	-2.86	8.013	-8.272	-2.86	8.019
-7.68	3.137	8.017	-7.68	8.038	8.183	-8.282	-2.86	8.013	-8.282	-2.86	8.019
-7.81	3.155	8.017	-7.81	8.651	8.192	-8.292	-2.86	8.013	-8.292	-2.86	8.019
-7.94	3.173	8.017	-7.94	9.251	8.200	-8.302	-2.86	8.013	-8.302	-2.86	8.019
-8.07	3.191	8.017	-8.07	9.851	8.208	-8.312	-2.86	8.013	-8.312	-2.86	8.019
-8.20	3.209	8.017	-8.20	10.451	8.216	-8.322	-2.86	8.013	-8.322	-2.86	8.019
-8.33	3.227	8.017	-8.33	11.051	8.224	-8.332	-2.86	8.013	-8.332	-2.86	8.019
-8.46	3.245	8.017	-8.46	11.651	8.232	-8.342	-2.86	8.013	-8.342	-2.86	8.019
-8.59	3.263	8.017	-8.59	12.251	8.240	-8.352	-2.86	8.013	-8.352	-2.86	8.019
-8.72	3.281	8.017	-8.72	12.851	8.248	-8.362	-2.86	8.013	-8.362	-2.86	8.019
-8.85	3.299	8.017	-8.85	13.451	8.256	-8.372	-2.86	8.013	-8.372	-2.86	8.019
-8.98	3.317	8.017	-8.98	14.051	8.264	-8.382	-2.86	8.013	-8.382	-2.86	8.019
-9.11	3.335	8.017	-9.11	14.651	8.272	-8.392	-2.86	8.013	-8.392	-2.86	8.019
-9.24	3.353	8.017	-9.24	15.251	8.280	-8.402	-2.86	8.013	-8.402	-2.86	8.019
-9.37	3.371	8.017	-9.37	15.851	8.288	-8.412	-2.86	8.013	-8.412	-2.86	8.019
-9.50	3.389	8.017	-9.50	16.451	8.296	-8.422	-2.86	8.013	-8.422	-2.86	8.019

Table 7.27

MORA	TEST 2045	MACH=1.10	FREQUENCY = 45. HZ	PRESSURE = 6.67 BAR	CP° / R=CP° / I=2.52					
					SECTION 21			SECTION 22		
SECTION 2E				SECTION 4E				SECTION 5E		
X	R	I	X	R	I	X	R	I	X	R
-0.012	-0.512	-0.586	-0.012	-0.157	-0.586	-0.012	-0.165	-0.295	-0.449	-1.3
-0.025	-0.556	-0.625	-0.025	-0.686	-0.755	-0.025	-0.898	-1.186	-1.69	-0.9
-0.053	-0.433	-0.505	-0.053	-0.268	-0.283	-0.053	-0.653	-0.863	-1.199	-0.8
2.157	-0.157	-0.221	2.157	-0.036	-0.221	2.157	-0.221	-0.298	-0.533	-0.7
3.365	-0.556	-0.625	3.365	-0.686	-0.755	3.365	-0.898	-1.186	-1.69	-0.9
1.626	-0.116	-0.186	1.626	-0.036	-0.186	1.626	-0.221	-0.298	-0.533	-0.7
0.659	-0.127	-0.197	0.659	-0.645	-0.715	0.659	-0.816	-1.106	-1.69	-0.9
0.879	-0.722	-0.811	0.879	-0.616	-0.701	0.879	-0.816	-1.106	-1.69	-0.9
0.722	-0.511	-0.597	0.722	-0.492	-0.582	0.722	-0.853	-1.149	-1.69	-0.9
0.524	-0.337	-0.424	0.524	-0.356	-0.442	0.524	-0.853	-1.149	-1.69	-0.9
0.511	-0.466	-0.542	0.511	-0.489	-0.532	0.511	-0.853	-1.149	-1.69	-0.9
0.466	-0.442	-0.518	0.466	-0.456	-0.505	0.466	-0.853	-1.149	-1.69	-0.9
0.456	-0.531	-0.606	0.456	-0.521	-0.589	0.456	-0.842	-1.132	-1.68	-0.8
0.566	-0.562	-0.632	0.566	-0.551	-0.615	0.566	-0.832	-1.122	-1.68	-0.8
0.562	-0.568	-0.644	0.562	-0.546	-0.611	0.562	-0.832	-1.122	-1.68	-0.8
0.546	-0.606	-0.684	0.546	-0.601	-0.645	0.546	-0.811	-1.111	-1.68	-0.8
0.606	-0.658	-0.742	0.606	-0.651	-0.637	0.606	-0.804	-1.096	-1.68	-0.8
0.658	-0.495	-0.576	0.658	-0.594	-0.676	0.658	-0.817	-1.096	-1.68	-0.8
0.495	-0.685	-0.767	0.495	-0.697	-0.778	0.495	-0.817	-1.096	-1.68	-0.8
0.685	-0.597	-0.678	0.685	-0.601	-0.644	0.685	-0.817	-1.096	-1.68	-0.8
0.597	-0.138	-0.218	0.597	-0.395	-0.471	0.597	-0.817	-1.096	-1.68	-0.8
0.598	-0.767	-0.848	0.598	-0.778	-0.859	0.598	-0.817	-1.096	-1.68	-0.8

Table 7.28

Table 7.29

NORA TEST 76 MACH=.90 FREQUENCY= 40. HZ PRESSURE=.60 BAR CP'/R=CP"/I=.98

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
.812	3.751	-1.126	.812	5.313	-1.457						
.825	1.673	-.8.342	.825	2.016	-.8.573						
.850	1.206	-.8.312	.850	2.182	-.8.508	.058	-1.572	.8.386	.849	-2.225	.8.511
.100	1.112	-.8.186	.100	1.319	-.8.188	.188	-1.178	.8.214	.108	-1.393	.8.218
.200	.852	-.8.046	.200	1.141	-.8.044	.268	-8.878	.8.053	.199	-8.996	.8.045
.280	.8.009	8.057	.280	.865	8.117	.280	-8.795	8.045	.285	-8.877	-8.004
.350	.8.752	8.126	.350	.853	8.169	.399	-8.081	-8.158	.400	-8.716	-8.255
.400	.8.733	8.172	.400	.769	8.285						
.450	.8.662	8.237	.450	.578	8.316						
.500	.8.584	8.329	.500	.349	8.347	.500	-8.598	-8.314	.501	-8.449	-8.384
.550	.8.463	8.339	.551	.254	8.385	.600	-8.318	-8.372	.600	-8.669	-8.322
.600	.8.316	8.378	.601	.133	8.330	.601	-8.023	8.327	.601	-8.001	-8.006
.650	.8.197	8.373	.651	.910	8.252	.700	-8.848	-8.337	.701	-8.001	-8.006
.700	.8.069	8.367	.701	.981	8.178						
.800	-.8.017	8.250	.801	.981	8.178						
.870	-.8.034	8.186	.871	.859	8.128						

Table 7.30

SECTION 2E			SECTION 4E			SECTION 2I			SECTION 4I		
X	R	I	X	R	I	X	R	I	X	R	I
.812	3.638	-.8.978	.812	4.891	-1.245						
.825	2.390	-.8.463	.825	3.371	-.8.636						
.850	.957	-.8.235	.850	1.746	-.8.336	.050	-1.371	.8.263	.849	-2.437	.8.670
.100	1.121	-.8.195	.100	1.241	-.8.218	.100	-1.075	.8.160	.100	-1.834	.8.593
.200	.8.762	8.098	.200	.886	8.200	.200	-8.509	-8.668	.199	-2.579	.8.987
.280	.8.551	8.069	.280	.963	8.206	.280	-8.887	8.178	.280	-8.728	.8.833
.350	1.567	8.155	.350	.771	8.083						
.400	8.622	8.088	.400	.746	8.072	.399	-8.498	8.072	.400	-8.961	.8.030
.450	.8.567	8.040	.450	.839	8.084						
.500	.8.561	8.078	.500	.956	8.063	.500	-8.558	-8.263	.501	-8.762	-8.152
.550	.8.813	8.053	.551	.792	8.066						
.600	.8.338	8.215	.601	1.226	8.312	.600	-8.693	-8.246	.600	-1.495	1.555
.650	1.172	8.028	.651	.905	2.543	.700	-8.952	1.826			
.700	.8.508	8.572	.701	.981	8.456	.871	-8.456	8.106			
.800	-.8.217	8.816	.801	.857	8.247	.871	-8.247	8.084			
.870	-.8.268	8.357									

CP'/R=CP"/I=2.98

PRESSURE=.60 BAR

CP'/R=CP"/I=2.83

PRESSURE=.60 BAR

CP'/R=CP"/I=2.83

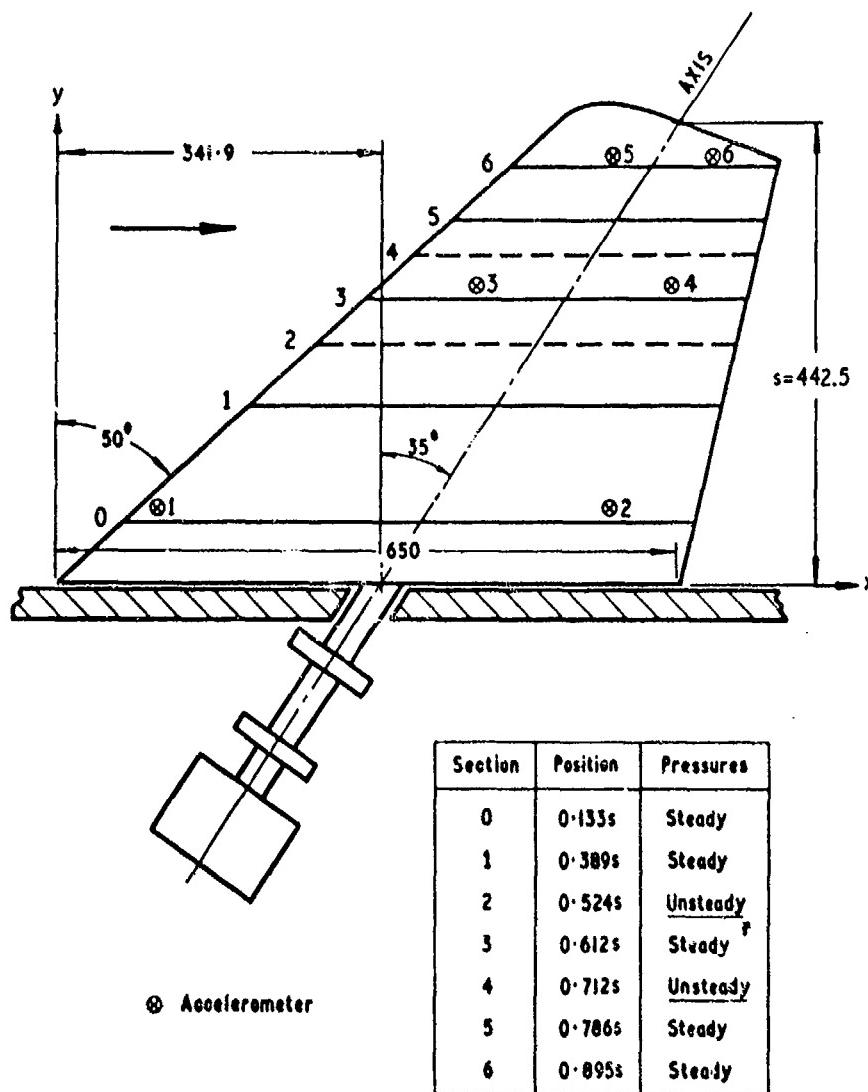


Fig 7.1 Model and rotary oscillator
(dimensions in mm)

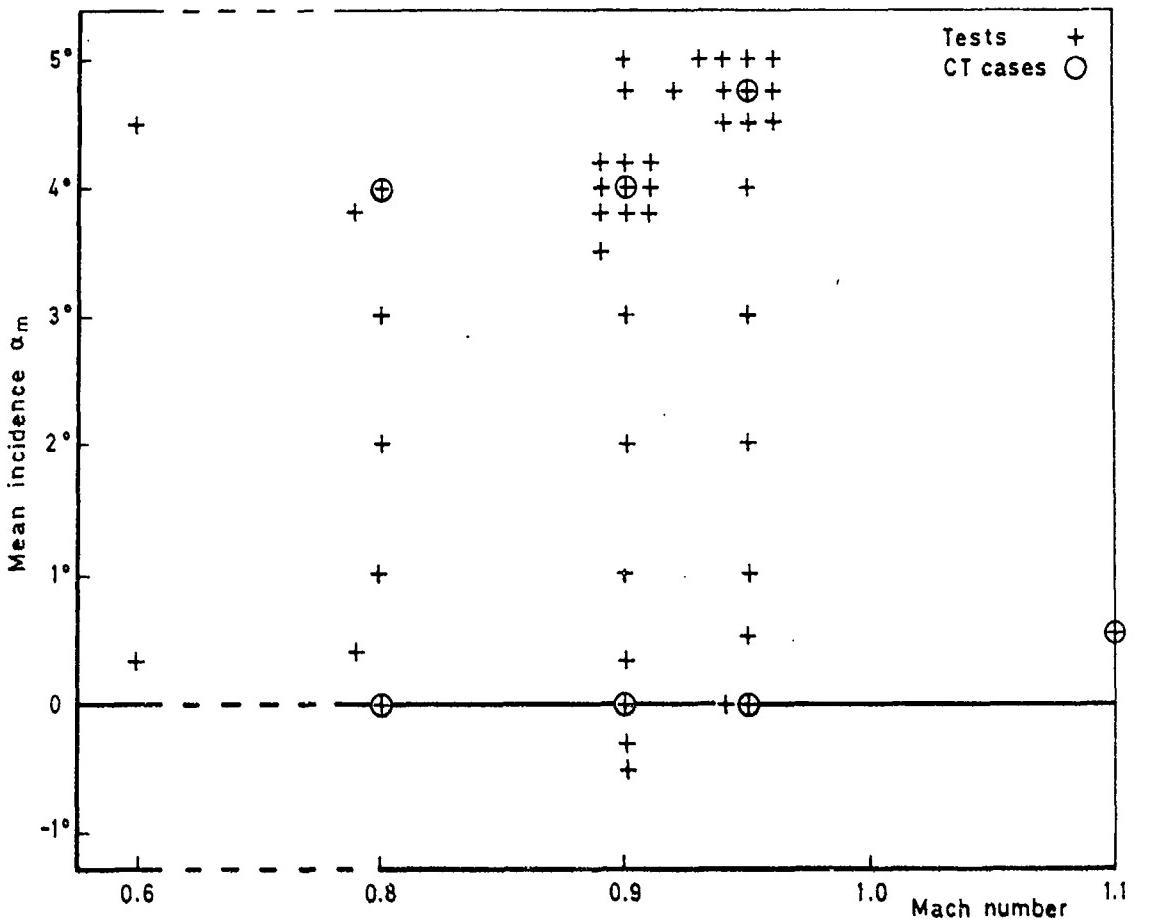


Fig 7.2 Test conditions and computational test cases

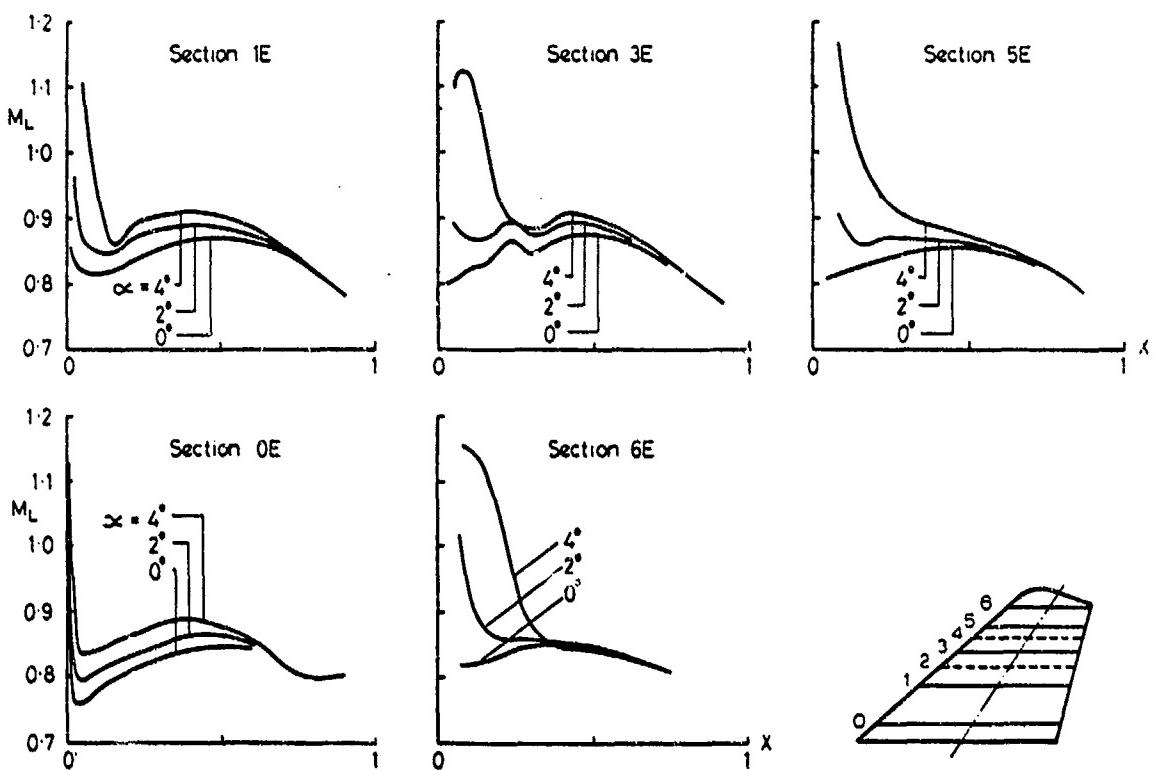


Fig 7.3 Local Mach numbers at upper surface, $M = 0.80$

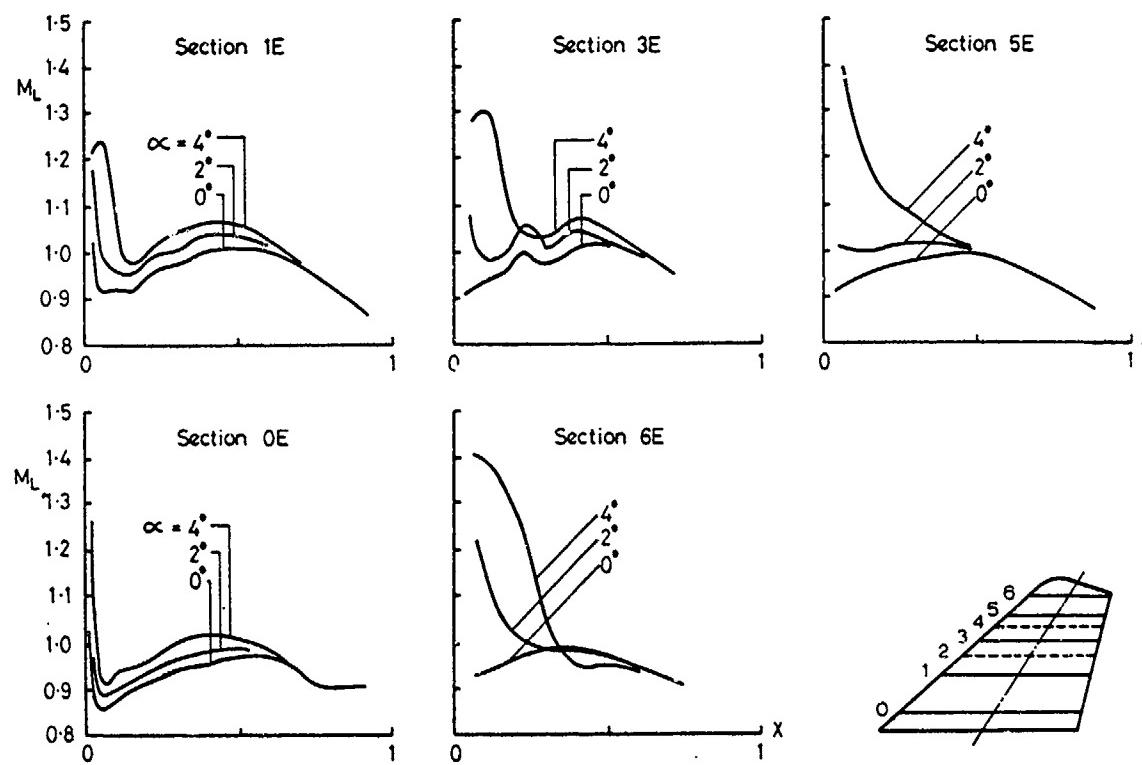


Fig 7.4 Local Mach numbers at upper surface, $M = 0.90$

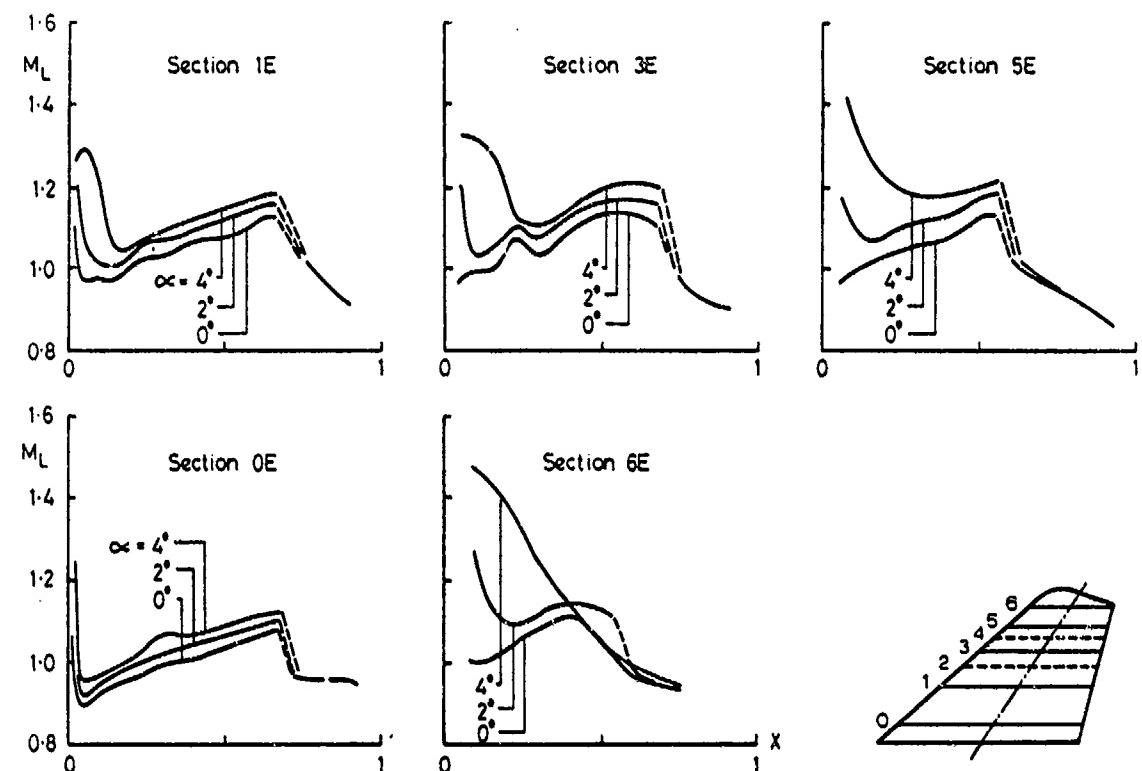


Fig 7.5 Local Mach numbers at upper surface, $M = 0.95$

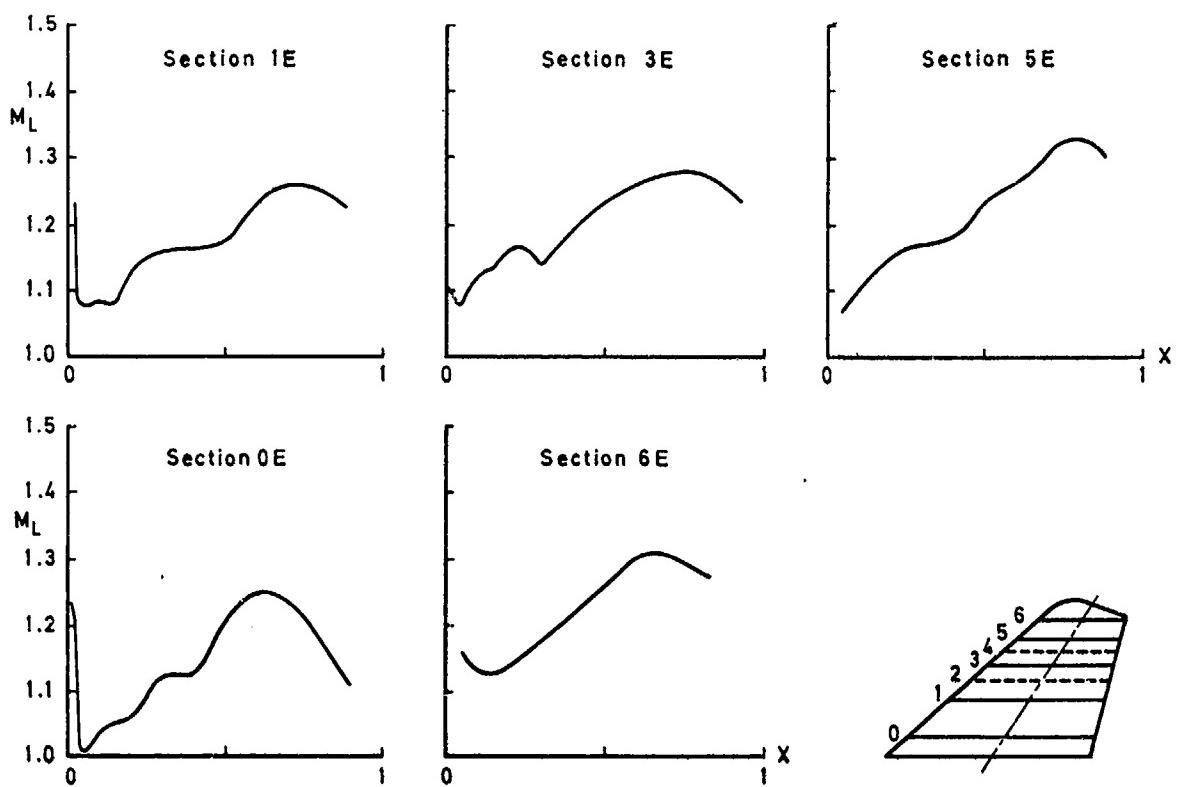


Fig 7.6 Local Mach numbers at upper surface, $M \approx 1.10, \alpha \approx 0$

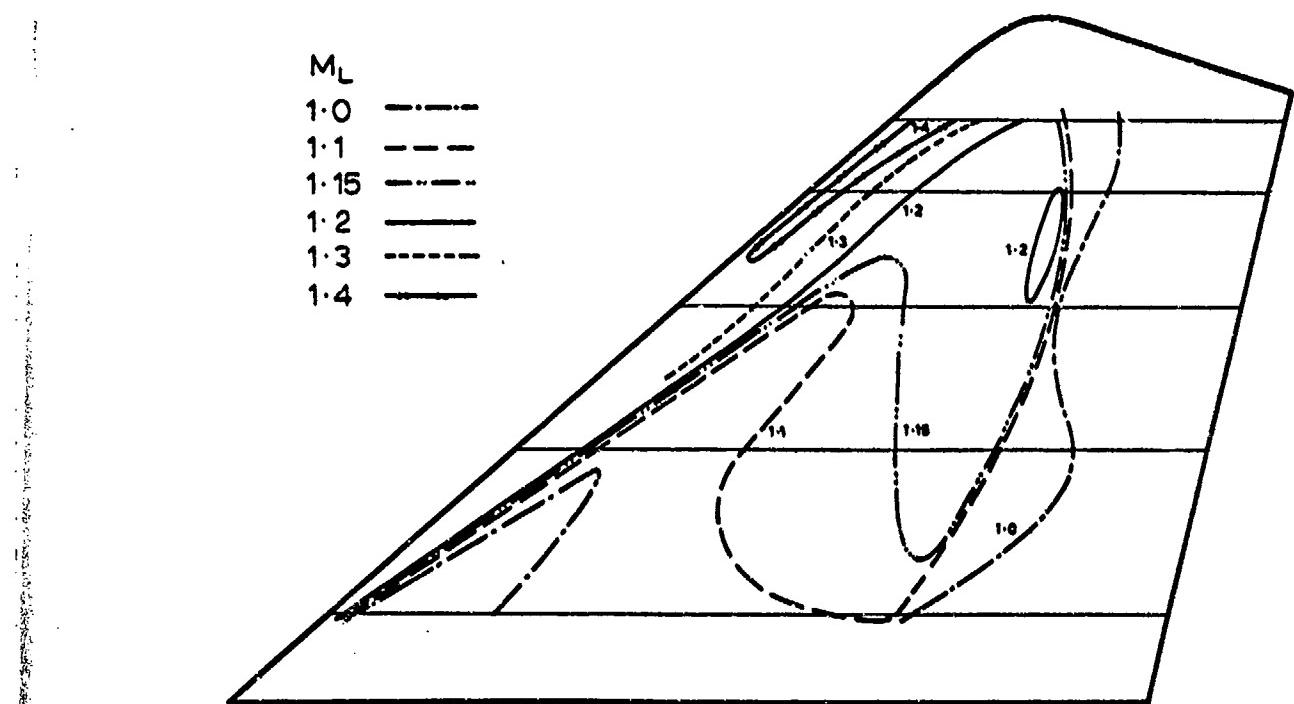


Fig 7.7 Isomachs, $M = 0.95, \alpha = 4^\circ$

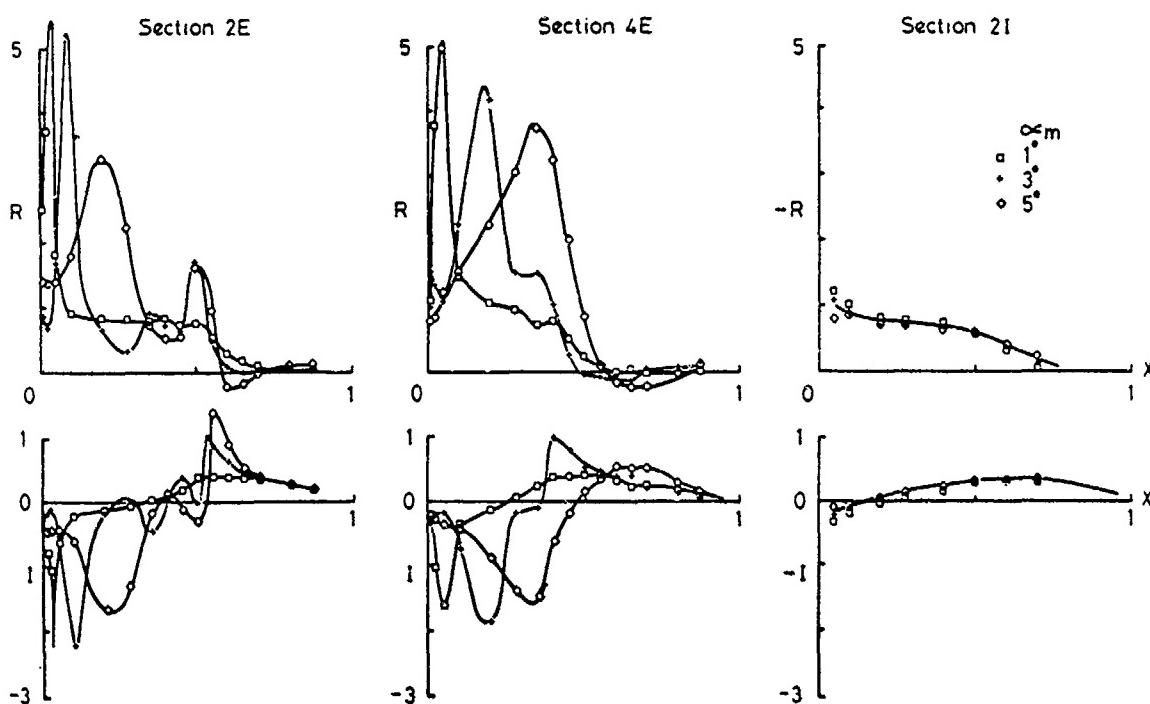


Fig 7.8 Oscillatory pressures. Influence of incidence, $M = 0.90$, $f = 40$ Hz

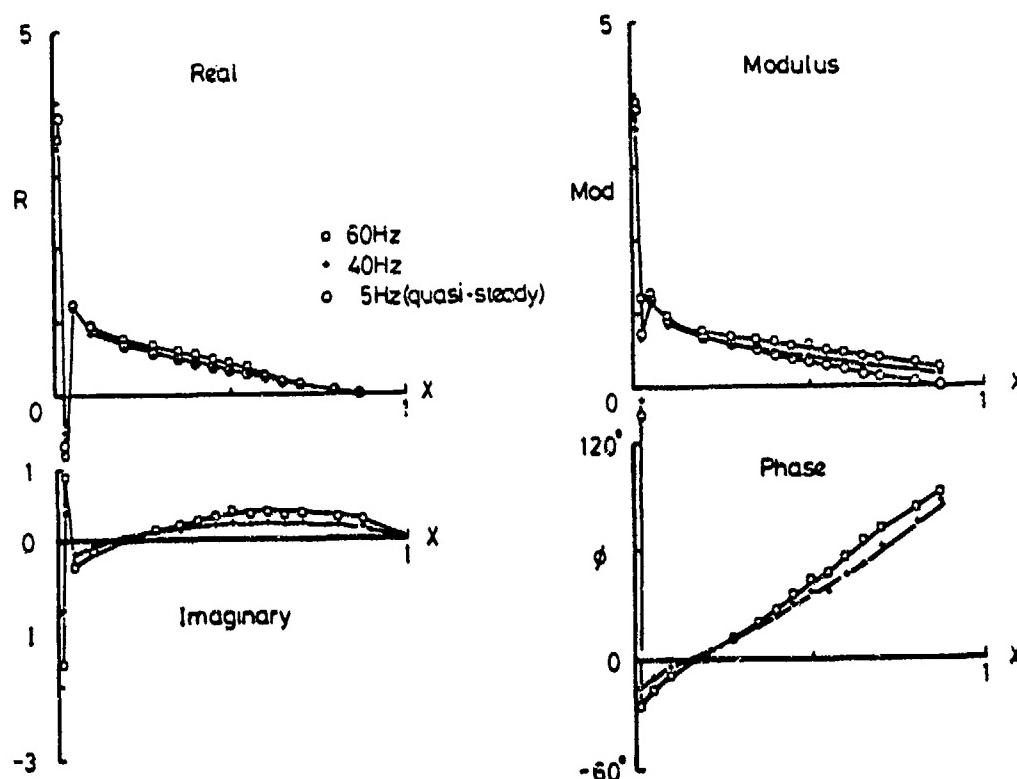


Fig 7.9 Oscillatory pressures, $M = 0.90$, $\alpha_m = 0$. Influence of frequency, Section 2E

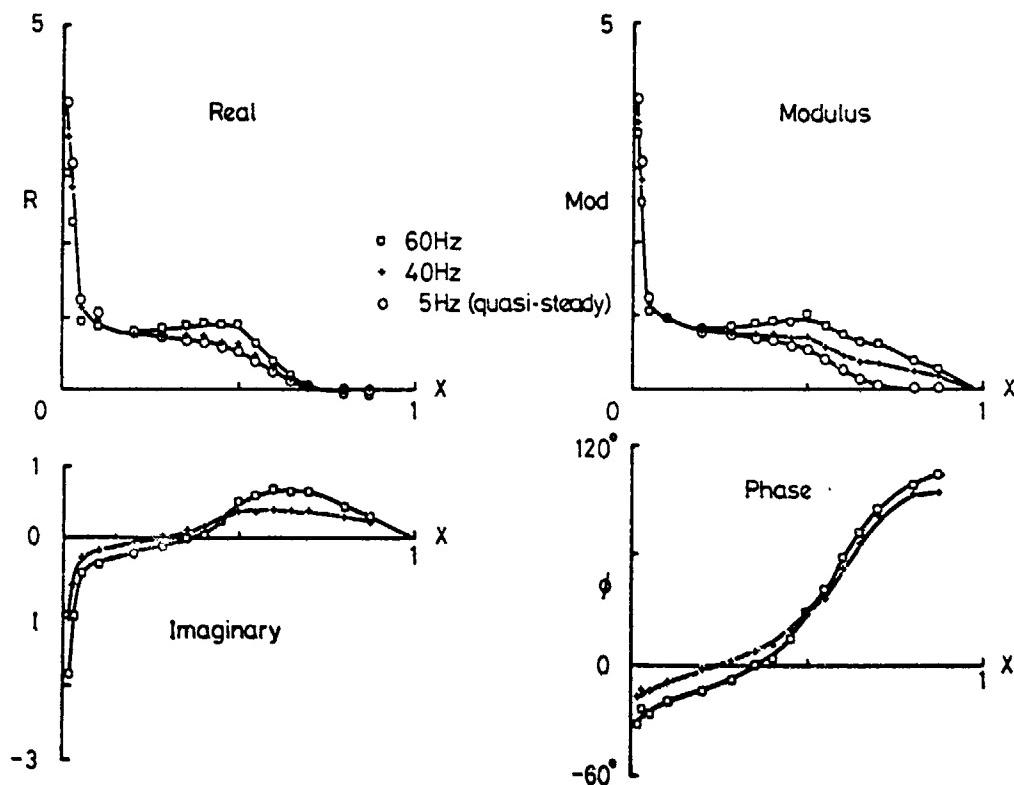


Fig 7.10 Oscillatory pressures, $M = 0.90$,
 $\alpha_m = 0$. Influence of frequency,
Section 2E

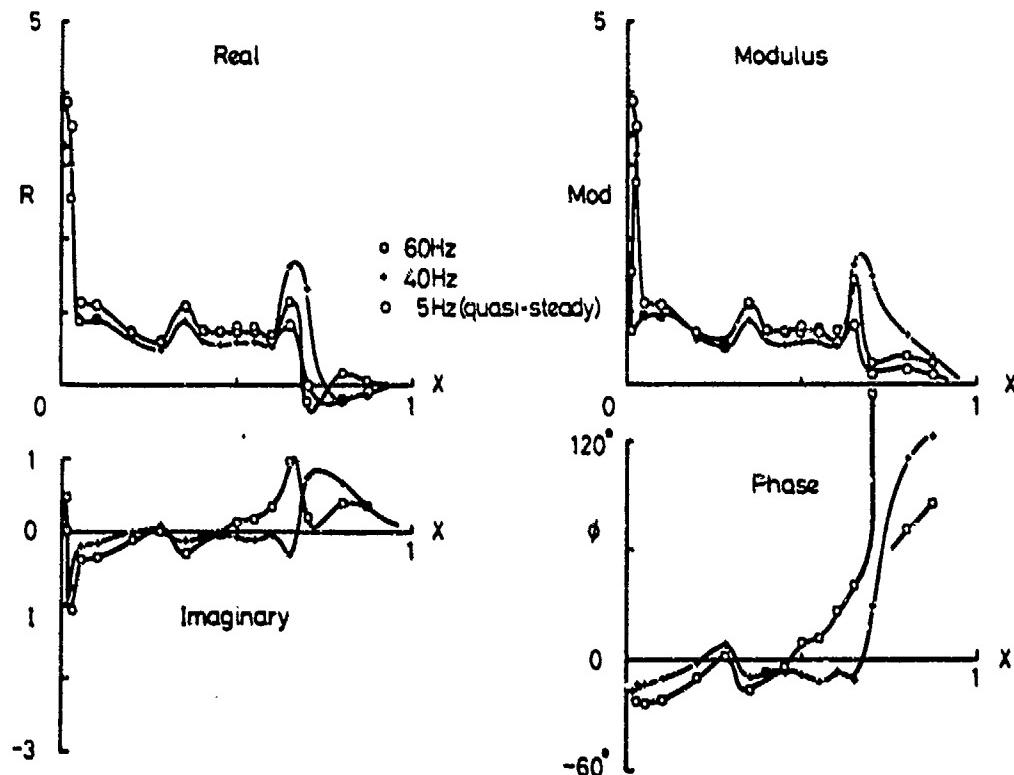


Fig 7.11 Oscillatory pressures, $M = 0.95$,
 $\alpha_m = 0$. Influence of frequency,
Section 2E

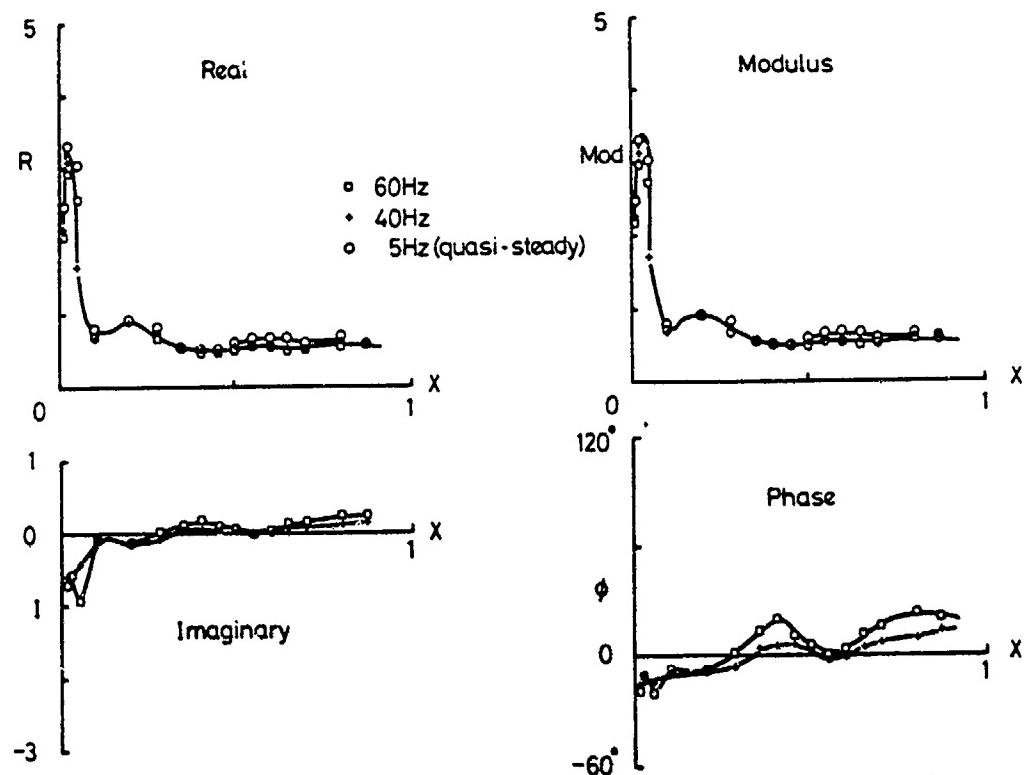


Fig 7.12 Oscillatory pressures, $M = 1.10$,
 $\alpha_m \approx 0.55^\circ$. Influence of frequency,
Section 2E

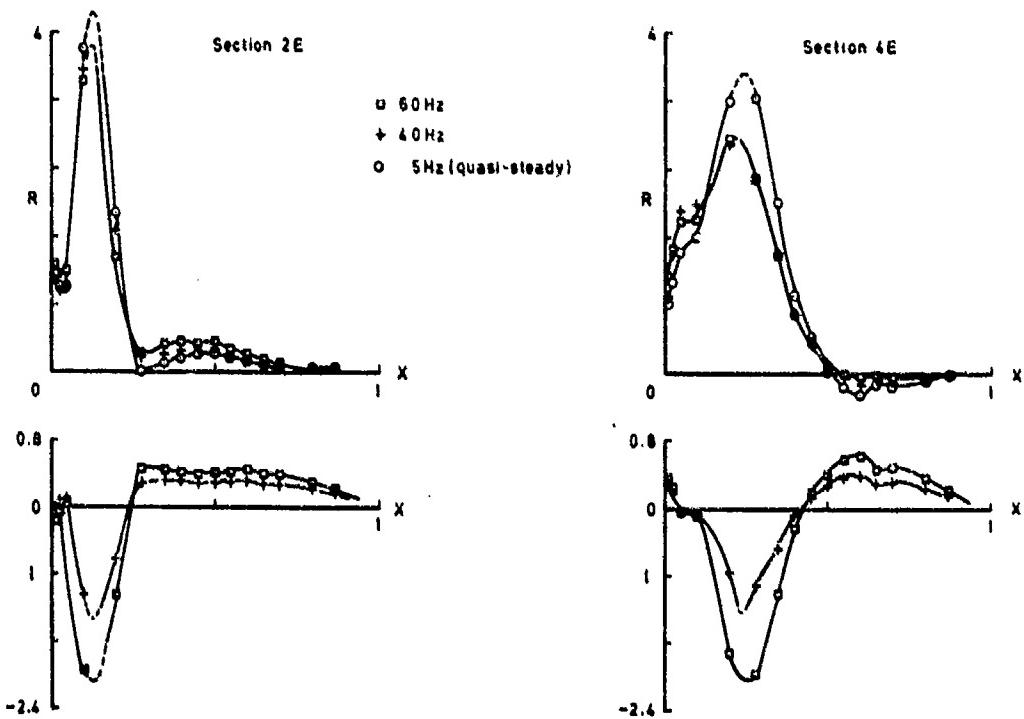


Fig 7.13 Oscillatory pressures, $M = 0.80$, $\alpha_m = 4.0^\circ$.
Influence of frequency

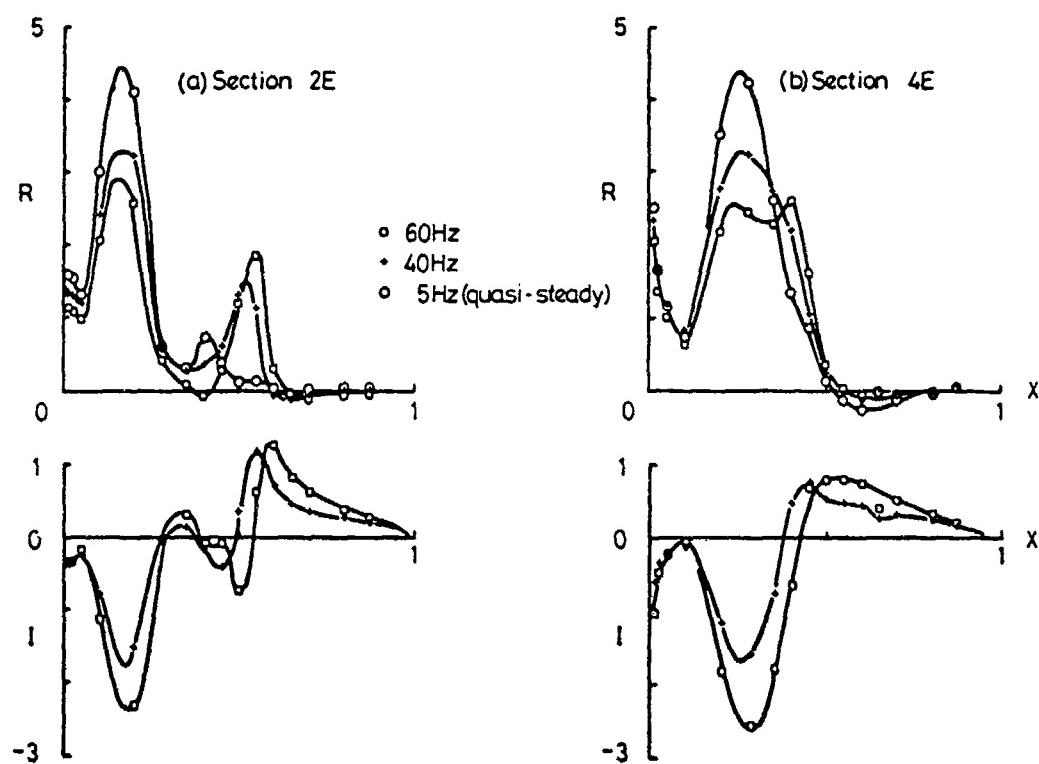


Fig 7.14 Oscillatory pressures, $M = 0.90$,
 $\alpha_m = 40^\circ$. Influence of frequency

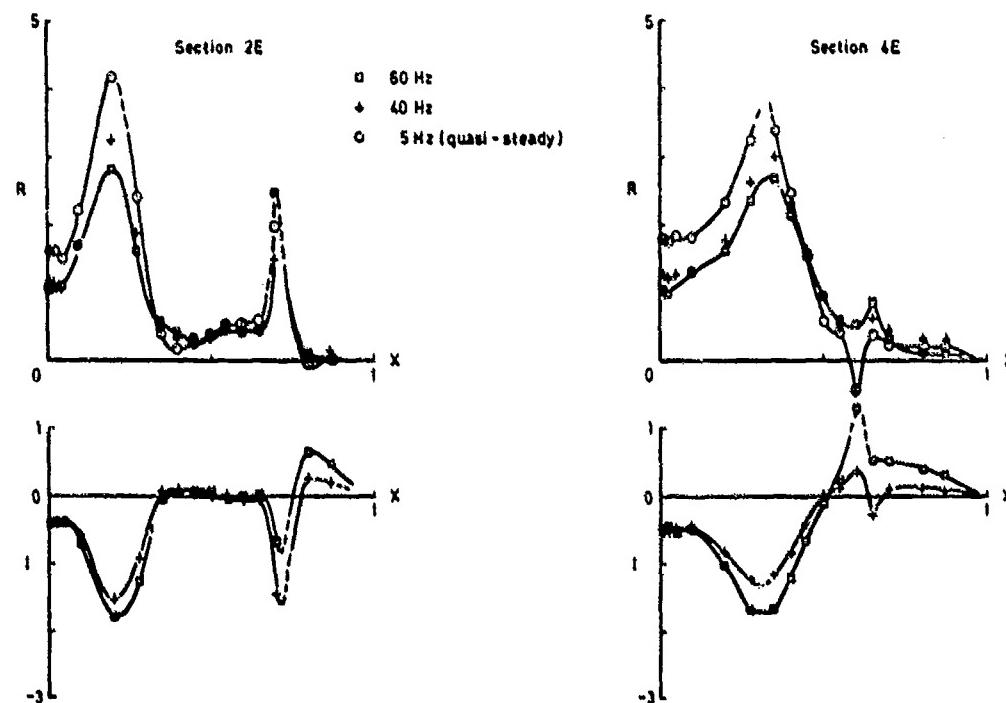


Fig 7.15 Oscillatory pressures, $M = 0.95$, $\alpha_m = 4.75^\circ$.
Influence of frequency

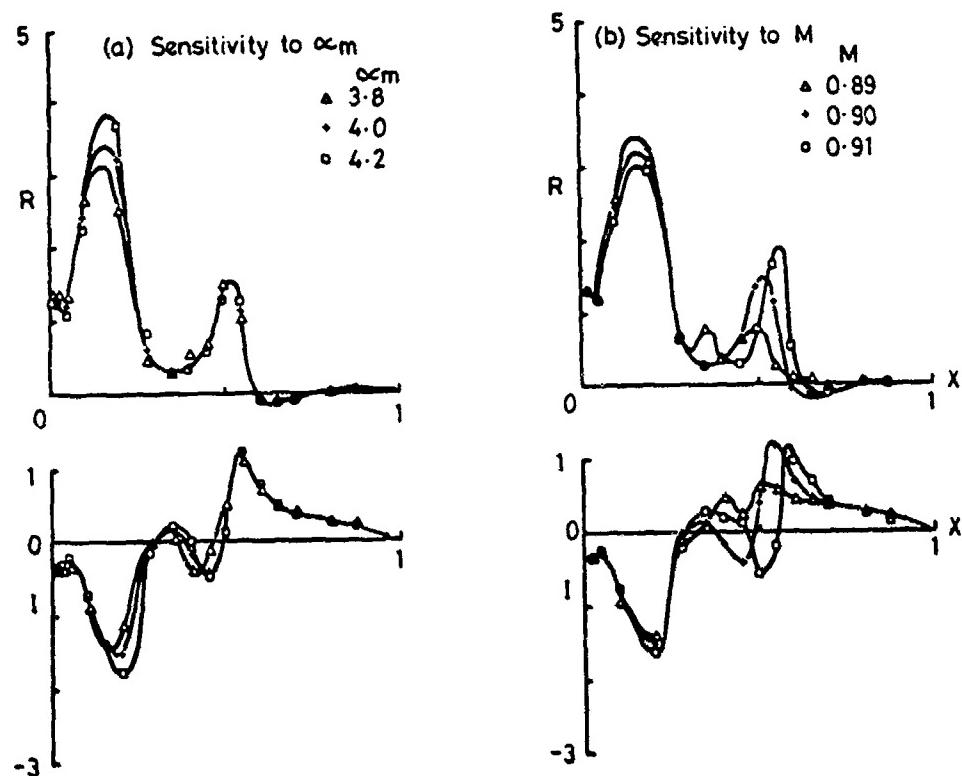


Fig 7.16 Oscillatory pressures. Sensitivity to small changes of incidence and Mach number. $M \approx 0.90$, $\alpha_m \approx 4^\circ$. Section 2E, $f = 40$ Hz

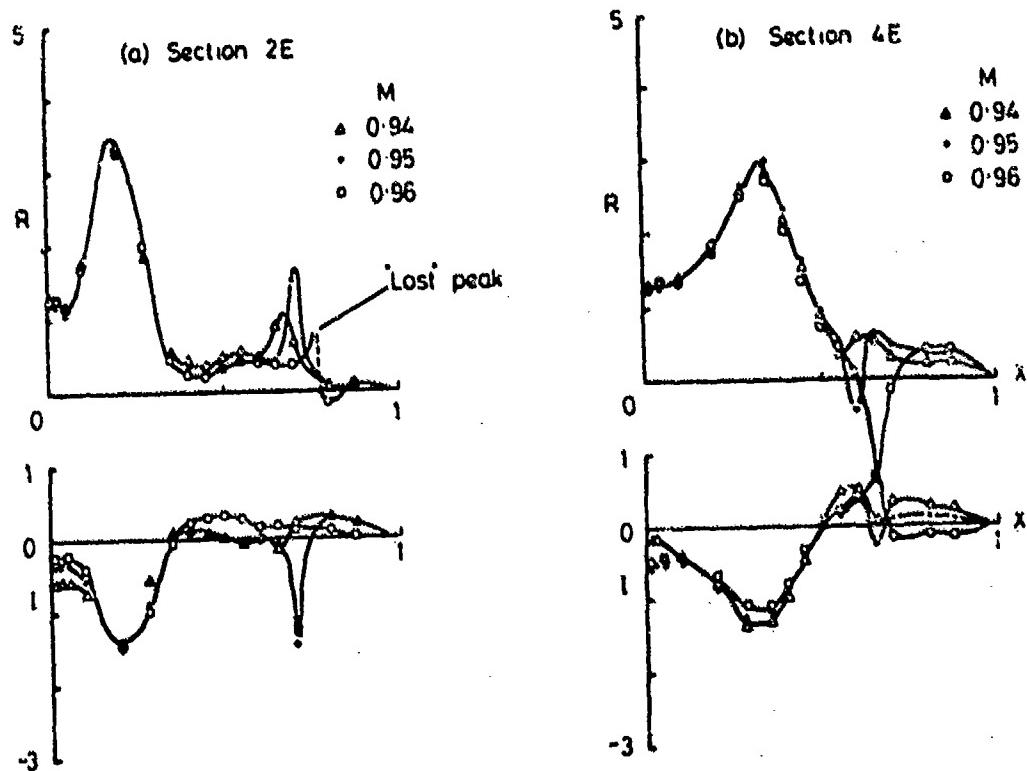


Fig 7.17 Oscillatory pressures. Sensitivity to small changes of Mach number. $M \approx 0.95$, $\alpha_m = 4.75^\circ$, $f = 40$ Hz

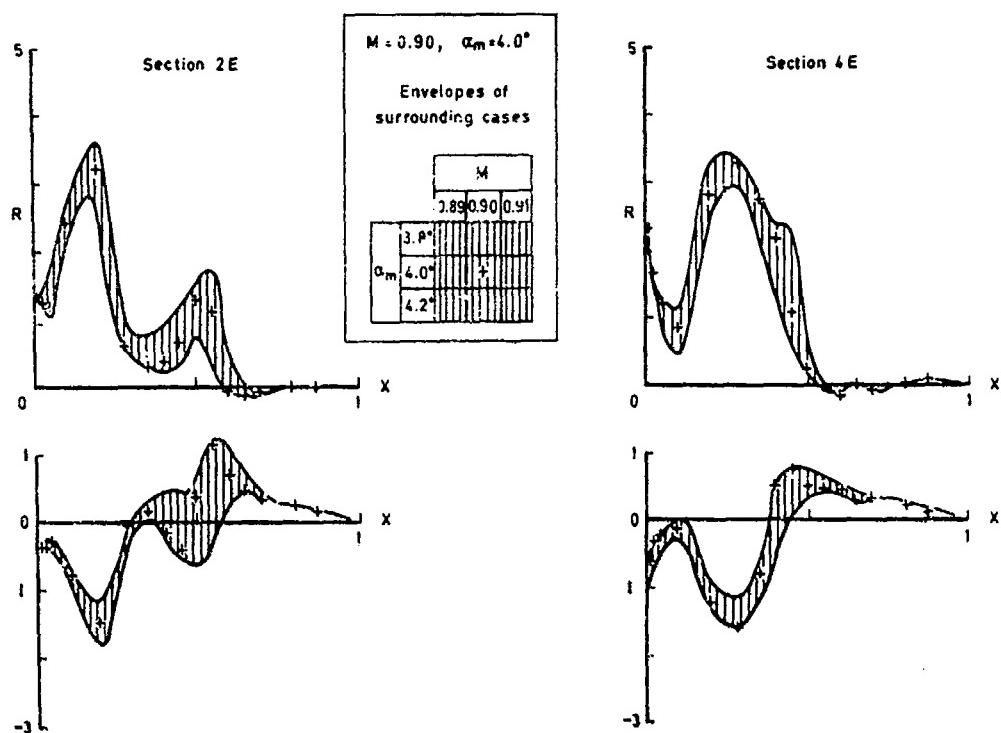


Fig 7.18 Oscillatory pressures for a matrix of cases centred on $M = 0.90$, $\alpha_m = 4.00$, $f = 40$ Hz

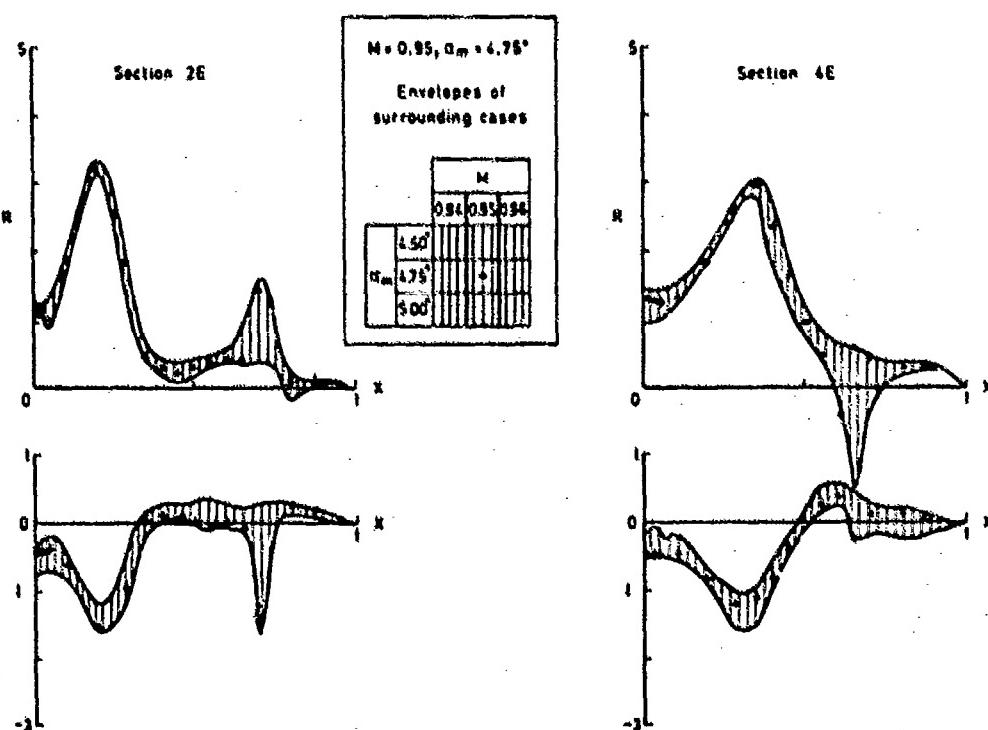


Fig 7.19 Oscillatory pressures for a matrix of cases centred on $M = 0.95$, $\alpha_m = 4.750$, $f = 40$ Hz

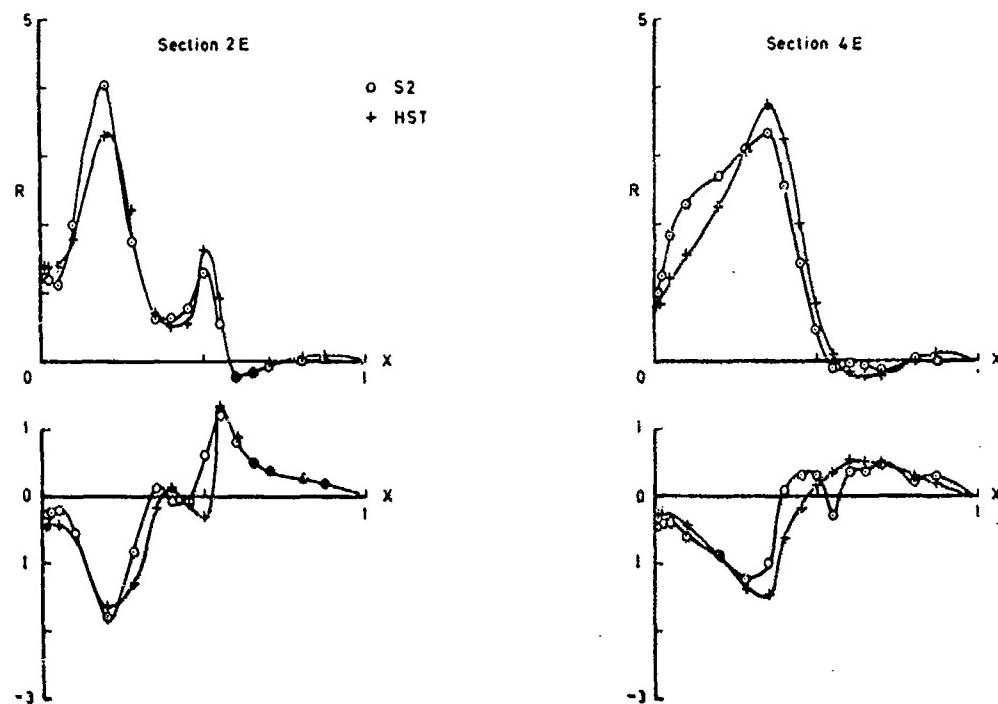


Fig 7.20 Oscillatory pressures. Comparison of data from S2 and HST.
 $M = 0.90, \alpha_m = 5^0, f = 40$ Hz

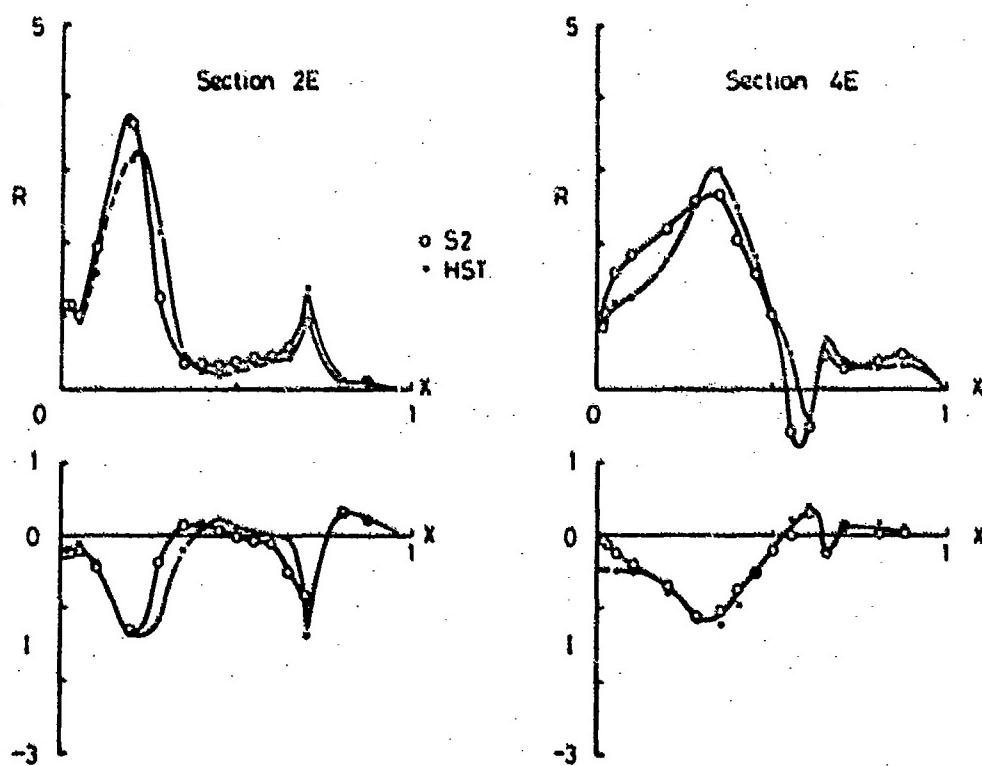


Fig 7.21 Oscillatory pressures. Comparison
of data from S2 and HST.
 $M = 0.95, \alpha_m = 5^0, f = 40$ Hz

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document								
	AGARD-R-702	ISBN 92-835-1430-0	UNCLASSIFIED								
5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly sur Seine, France										
6. Title	COMPENDIUM OF UNSTEADY AERODYNAMIC MEASUREMENTS										
7. Presented at											
8. Author(s)/Editor(s)			9. Date								
	Various		August 1982								
10. Author's/Editor's Address			11. Pages								
	Various		196								
12. Distribution Statement	This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.										
13. Keywords/Descriptors	<table> <tr> <td>Aerodynamic characteristics</td> <td>Aerodynamic configurations</td> </tr> <tr> <td>Unsteady flow</td> <td>Experimental data</td> </tr> <tr> <td>Transonic flow</td> <td>Applications of mathematics</td> </tr> <tr> <td>Aeroelasticity</td> <td></td> </tr> </table>			Aerodynamic characteristics	Aerodynamic configurations	Unsteady flow	Experimental data	Transonic flow	Applications of mathematics	Aeroelasticity	
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<p style="text-align: center;">7-36</p>											

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